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MINUTES OF PROCEEDINGS

OF THE

INSTITUTION

OF

CIVIL ENGINEERS;

WITH

ABSTRACTS OF THE DISCUSSIONS.

Vol. XXIV.

SESSION 1864-65.

EDITED BY

JAMES FORREST, Assoc. Inst. C.E., Secretary.

Index, Page 547.

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THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1864-65.

November 15, 1864.

JOHN ROBINSON M'CLEAN, President,
in the Chair.

No. 1,122.—"On the Decay of Materials in Tropical Climates, and the methods employed for arresting and preventing it."[1]—By GODFREY OATES MANN.

THE cause of the decay of materials in tropical climates, and the means successfully employed to prevent such decay, must become an increasing matter of interest to the Engineer, as well as to the English capitalist, not only from the rapid increase of public works in India, but also from the connection of Great Britain with the extensive and rising empire of Brazil, with reference to which this Paper is especially written.

The climate of Brazil is the most agreeable of any within the tropics, either in the western or in the eastern hemisphere. This is especially the case in the province of Pernambuco, where, probably, the temperature varies less than in any other quarter of the globe, as—

The average temperature in the night during the year is 64°.
The average temperature in the shade during the rains is 78°.
The average temperature in the shade during the hot season is 82°.

The highest temperature in the sun during the year is 148°.

The seasons, which, without doubt, influence more than the temperature the decay of materials, cannot be said to be so regular, as regards particular months, as in India, or as to the quantity of rain falling during the year. The annual rainfall varies from 60 inches to 120 inches. Thus, in 1860, 67 inches fell, whilst in

[1] The discussion upon this and the following Paper occupied portions of two evenings, but an abstract of the whole is given consecutively.

1861, the rainfall amounted to 123 inches. In some years the rains commence unusually early, continue for a month or more, after which there may be a month, or even two months of hot weather; when the rains again set in for a short, or a lengthened period. In other years the rains commence late, and last only a short time; or set in early, and continue for a long period, with intervals of days, or perhaps weeks, of sun, causing that peculiarity in the climate, excessive heat combined with much moisture, noticeable, more or less throughout the year, and which must be very trying for the generality of materials, more particularly railway sleepers, about which it is proposed first to treat.

The first lengths of the permanent way of the Pernambuco Railway were laid in February, or March, 1857, with creosoted sleepers of timber from the north of Europe. Fair average samples, taken out on the 1st December 1863, show that the half round intermediate sleeper is in the most perfect state of preservation, in fact, nearly as good as on the day it was put down; while the square sawn, or joint sleeper has not withstood the effects of the climate so well. Although the square sleeper does not exhibit a very favourable result, there can be no doubt as to the advisability of sending out, in the first instance, to India, Brazil, or any other tropical climate, in which a railway is being made, the whole of the materials required for the permanent way, as the Engineers and the contractors' agents, are, in most cases, unacquainted with the qualities of tropical timber, and the locality is generally unable to supply timber of good quality, in sufficient quantities, for the rapid construction of a line. Even if the required quantity could be obtained, the natives are so well versed in the question of supply and demand, that the native timber quickly assumes the price of imported creosoted sleepers. It is evident, from a sample which had been laid nearly seven years before removal, that creosote will, if properly applied to suitable descriptions of timber, prevent its decay in tropical climates.

The points requiring consideration are, the quality and form of the sleeper, and the kind of ballast in which it will be most advisable to lay it. About 12 miles of the Pernambuco Railway are entirely laid with creosoted sleepers, principally in white sand. In this description of ballast, the half-round sleepers have suffered since the opening of the first section of the line in 1858, a depreciation of not more than 1 per cent., whilst the square sawn sleepers have experienced a depreciation of not less than 50 per cent. Had the latter been placed in wet cuttings, with ballast retentive of moisture, no doubt the whole of them would have required to be renewed. Hence it is evident, that the smaller and closer grained wood is much more lasting than the larger and more porous description; and that fine open sand ballast, which

allows a free drainage during the rains, is best adapted for the preservation of sleepers in the tropics. This has been satisfactorily proved in 10 miles of road laid with creosoted and with native sleepers, in a mixed description of ballast, in which neither has stood so well as in the fine sand.

As regards the form, the general opinion in Pernambuco is in favour of the half round, as it allows the water, during the wet season, to pass away more freely, than is the case with the square sawn sleeper.

In 1859, whilst the works of the second section of the Pernambuco Railway were in progress, the Government Engineer Fiscal, Signor Manoel de Barras, advised the use of native sleepers; but, beyond giving a list of those timbers he considered suitable, he did not, in any way, assist the Company's Engineer with any facts as to the peculiarities of these timbers. The result was, that the wood was cut at unfavourable seasons, and the progress of the works being rapid, the sleepers had not time to dry, but were used in a perfectly green state, so that shortly after the opening of any section, the renewal of the sleepers had to be commenced. On the fourth and last section, this took place within a month after it was opened.

From this it might be inferred, that there does not exist in Brazil timber, either in quality or quantity, fit for railway purposes; but such is not the case, as there are numerous qualities of the finest wood in the world, and about as inexhaustible as the coal-fields of Great Britain.

The question may be asked, why then has this supply not been made available? In reply, it may be said, that there is an entire want of all statistical or reliable information amongst the people themselves. They continue to employ what their forefathers used, and if it serves their purpose, they have not the least desire to find out anything better, or more available. This seems to obtain in all tropical climates, so that the railway pioneer finds himself without data to guide him, and it is only after a residence of many years in any one of these countries, that personal and gradually acquired experience can guide the Engineer to a judicious use of the resources of the country, and insure his not committing any serious error.

Railway sleepers being a new feature in Brazil, the railway Engineers had to seek for information, as to the durability of the innumerable varieties of timber existing in the country. The result was, that scarcely two opinions were found to agree; ignorance or cupidity in most cases influencing the information given. Consequently most unsuitable descriptions were used, which now (as previously stated), after being laid but a short time, require extensive renewals. Still, some of the samples afford evidence, that

there is wood in Brazil that will last for an indefinite period. The opening of the railways into the interior will doubtless bring this superior description of wood to the various sea-ports, as is now the case on the Pernambuco Railway, to the exclusion of all imported timber. The Author, after nearly seven years' experience, is confident that properly selected timber of the country will be found more durable than any description of wood sleeper yet imported; and, as resident Engineer of the Pernambuco Railway, he is now employing these kinds in renewing the sleepers on the line.

In conclusion, upon the subject of native railway sleepers, it is found advisable, in order to prevent decay, to cut the timber during the dry season, to select large and full-grown trees, to remove the whole of the bark and sapwood, leaving the heart only, and not to expose the sleepers in the sun when first cut, but to stack them in open piles under cover, through and about which the air can freely circulate for a few months. These rules being attended to, the result will be satisfactory, as regards Brazilian timber, and it is reasonable to assume, that the same rules will apply, more or less, to timber in India, and other tropical countries.

The cost of sleepers delivered, subject to these conditions, at the various stations on the Pernambuco Railway is at present 2*s.* 7*d.* each, the scantling being sometimes 10 inches, by 5 inches, by 9 feet, but more frequently 12 inches, by 6 inches, by 9 feet. Imported creosoted sleepers have invariably cost double that amount.

From what has been said with regard to railway sleepers, it will be evident, that timber in general requires in tropical climates, the greatest consideration in its use for permanent structures. Reliable information may perhaps be obtained, as to the best descriptions for general use; still the Engineer will meet with such a variety of opinions among the natives, that it is only after considerable personal experience, that he feels certain in using any description for particular purposes. Good timber suitable for building abounds in Brazil, in the greatest variety. Many kinds are impervious to the white ant, which insect generally selects the more porous woods, and especially if these are in contact with the earth. In dry places, and with a free circulation of air, the white ant does not prefer timber thus situated; and it is found that roofs of buildings, of good and well-seasoned native wood, resist, for an indefinite period, both the climate and the white ant.

Creosoted timber, it is well known, resists the attacks of the white ant; but the close grain of the generality of tropical timber renders any attempt to creosote it all but useless. North American pitch-pine also stands exceedingly well the attacks of the white ant, when used in the roofs of buildings, or in any locality not humid;

but it is found after a time, when laid upon the earth, to lose its resisting powers, as well as to become subject to rapid decay.

White, or yellow, pine can only be used in the tropics for doors, movable window frames, bodies of railway wagons, or other work intended to be kept in motion. Its use even for these purposes is questionable, as the white ant has such an affinity for it, that a door or a window which has remained shut for a few weeks, will almost invariably be attacked by that insect. Generally it will be best to select suitable native wood for all permanent works. Since the opening of the railway in Pernambuco, timber can be brought 70 miles or 80 miles from the interior, and be delivered of any practical scantling, at the rate of 1*s.* per cubic foot.

Since the establishment of the gasworks in Pernambuco, the Brazilian Engineers and constructors have adopted the practice of 'paying' over, with coal tar, the ends of all timbers built into the gables of buildings, or in any other position in which it is buried, or excluded from the air, and so far apparently with beneficial results.

The oldest samples of native timber that could be obtained accompany this Paper, and are part of the piles, taken up during the month of November, 1863, of the old Recife wooden bridge, constructed in 1614, and now about to be replaced by an iron bridge, under the direction of Mr. W. Martineau (M. Inst. C.E.)

It is only necessary to add, as regards this part of the subject, that to insure satisfactory results, it will be essential to select the quality suitable for any particular description of work, to see that the wood is cut at the proper season, and, to prevent its splitting, not to expose it to the sun when first cut; to have all the bark and sapwood removed, and to allow it to dry a certain time before being used. With these precautions no foreign timber will be found able to compete, in the tropics, with that of native growth.

Upon iron bridges, from their increasing adaptation, any information as to the result of their use in tropical climates must be very desirable. The merits of the different forms will not be discussed, as each may be said to be equally liable to decay. There is, however, one great defect in the construction of some of these bridges, that is, suspending the transverse girders by bolts, instead of allowing them to rest on the main longitudinal girder. When the two plans are compared, the most casual observer must give the preference to the latter, particularly where iron is so subject to rust if not properly treated.

Iron bridges in the tropics will, if proper care be taken in the first place, and ordinary attention be bestowed upon them afterwards, last for an indefinite period, whether on the sea-board, or in the interior; but in the latter locality, they will always show more favourable results. Under either of these conditions, it will

be found desirable, wherever practicable, to construct the piers of stone, in preference to using iron piles, as the latter will be found to be the first destroyed. In the province of Pernambuco, there are no examples of old iron bridges; in fact, except the St. Isabel, completed in 1863, by Messrs. Horace Green and Co., there are no other iron bridges than those of the Pernambuco Railway, four of which, when examined, showed the following results:—In these bridges the piers are formed of four cast-iron pipe piles, each 15 inches in diameter, to which were afterwards added two cylinders, each 3 feet in diameter, sunk on each side of the original pier, with columns and side brackets to the girders, an addition that was found necessary after the line had been opened for traffic. The superstructure, in most cases, is composed of Warren's girders.

The first bridge over the Pirapama River, about 16 miles from the city terminus, consists of two spans of 60 feet each. The iron piles below the water level were found to be coated with a thin layer of mud, similar to that of the bed of the river. When this was washed off, the piles appeared to be in a most perfect state, and not in the least rusted, in fact in as good preservation as when first put down. The bolts and nuts connecting the piles, the wrought-iron tie-bars for bracing the columns, as well as the whole of the upper structure, were also found to be in the most perfect state. The water in this river, although affected by the rise and fall of the tide, is at all times fresh, both near, and for some distance below, the bridge.

The second bridge consists of three spans over the Saboatão, a tidal river, which at the site of the bridge is salt, or more or less brackish, except at the lowest tides, when it is sometimes found to be fresh. Here the piles under high water were covered with small marine shells, not to any great thickness, and easily removed, when the red paint was found to be as perfect as when first applied. The iron itself did not seem to have been in the least affected. The wrought-iron bracing bars, 3 inches by $\frac{5}{8}$ inch, were not in such good preservation, rust being observed on them after the shells were removed. The whole of the upper structure was in a good and satisfactory condition.

The next bridge that came under examination was one of five spans, over the mouth of the river Ibura, at the head of Recife Harbour; and the fourth and last, of six spans, over the Capibaribe, a few hundred yards from the former, and as the result in both was exactly alike, they may be jointly described. At the time of the examination, the tide was very low, the bed of the river being nearly dry, so that the pipe-piles could be examined down to the sand. The whole of these were densely covered with oysters from 6 inches to 12 inches thick, and the first ones had adhered so

firmly to the piles, that on breaking them with a hammer, portions of the backs of the shells remained, requiring a chisel to get them off. When these were all removed, it was satisfactory to find that the piles were perfectly sound. These shells appear to act as preservatives to the metal, by excluding the air and the sea water. There is no doubt further examinations will prove, that these shells afford probably a better protection than any composition that could be put on, and therefore ought not to be removed. The wrought-iron bracing bars in these bridges do not, as may be expected, show so well as the cast-iron piles. A sample from the end of the bar attached to the pile-joint below the water line accompanies the Paper. It will show to what extent these bars have been affected, after being erected about six years, as well as illustrate how the shells adhere to the piles. The upper structure of these bridges was found to be in the best possible condition, and the result of the examination on the whole was very satisfactory.

It may probably be necessary in a few years to renew some of the wrought-iron bracing bars, as well as some of the bolts and nuts under water. When these require renewing, it will be advisable to use steel in place of wrought iron, as that material will no doubt endure as long as the bridge lasts. The result of six years' experience is certainly but a short time upon which to form a decided opinion ; but it would appear, that the cast-iron pipe piles are likely to last for a considerable period, and that the upper structure of wrought iron, with ordinary care and attention, is also likely to stand well. The only parts apparently affected are the wrought-iron bracing bars and the bolts and nuts below high-water mark. These may in future be made of steel with but little additional expense.

No special means appear hitherto to have been employed, or to have been considered necessary, for the preservation of iron bridges sent to the tropics. Red lead, or any other description of paint that came to hand, appears to have been used, and no consideration seems to have been given to the condition, or state of humidity, of the ironwork when painted. In consequence, after the sea voyage, owing to the high temperature and the 'steamy state of the ship's hold, rust is formed underneath the paint; the latter rises in blisters, then bursts, and falls off in large flakes, exposing the bare iron, highly oxidised, without a vestige of the paint remaining. This not only takes place with bridge-work, but also with locomotive engines and tenders, wrought-iron tanks, &c., when sent out completely painted. No doubt the same care is bestowed upon them as when intended for home use, but it would be better not to go to this expense, as it only entails further outlay in a short time, to scrape the whole off and commence

afresh. Care should be taken, in every description of work, that the iron be perfectly dry before the paint, or any other composition, is laid on. After trying a variety of paints, coal-tar was at last resorted to, for the preservation of the iron bridges on the Pernambuco Railway, and so far apparently with good success. From the result of its application in several other descriptions of work, the Author does not hesitate to recommend its use as the most efficient protection for bridges and iron work in general for the tropics. In order to remove the great and first source of mischief, moisture, or incipient oxidation on the surface of the iron, it will be advisable to have the whole of the smaller parts of the bridge-work, &c., before being sent away for shipment, heated to a low temperature, by passing them through a furnace or otherwise, then brushed and dipped in tar. The larger parts, which it would be inconvenient to heat, should be well cleaned, and the tar laid on as hot as possible. Tar of course can only be employed where it is decided to continue its use for the future preservation of the bridge. With public bridges, or in any situation where ornamental painting is considered necessary, linseed oil may be used instead of, and in the same way as, tar. Over this, and for further protection, a thin coat of zinc paint may be laid. This will stand the sea voyage, and when the bridge is erected, it can be cleaned off, when the ironwork will be ready to receive the finishing coat, which should also be of zinc, as all other paints for tropical climates are perfectly useless.

It is to be hoped that tar, linseed oil, and zinc paint, will all shortly be superseded by galvanising the whole of the bridge-work for the tropics, by which process more efficient protection will be afforded than by any other.

With regard to building materials, stone, when obtainable of good quality, is the most desirable, in all respects, for a tropical climate; and with the excellent lime of Brazil, and the still better 'chunam' of India, good stone-work in these climates is the most likely to last, with the least outlay for repairs. Stone ought never to be lost sight of by the Engineer, whenever its use is at all practicable. Abutments for bridges will, of course, be built of this material when it is obtainable, and, as previously stated, when practicable it is also to be preferred for the piers, instead of cast-iron piles. Stone has never been extensively used in or about Recife, owing to its being found only at a considerable distance from the city. It is imported from Portugal, for facing the churches. These, and a few old Dutch works of the seventeenth century, show how well this material stands the decaying influence of the tropics. It need scarcely be said, that no mistake can possibly be made in allowing it to enter freely into the construction of all public works in these climates.

Bricks, when stone cannot be obtained, must of necessity be used for certain descriptions of work. Great caution should be exercised in their selection, as it is found that all bricks made near the sea-board, with brackish water, are exceedingly susceptible to the weather, and moulder rapidly away when exposed. It is, therefore, advisable to make them at some distance from the coast, with fresh water, and above all to have them well and thoroughly burned, which, in these climates, where fuel is generally expensive, is most difficult to insure. Near to the sea-coast, it is found necessary to protect all brickwork with plaster, which certainly serves its purpose exceedingly well. In the interior of the country well-burnt bricks may stand for a few years, but ultimately it will be necessary to plaster them, or to give them a thick coat of whitewash from time to time. Tar, over a coat of whitewash, has been used with considerable success, for the protection of brick buildings, and other works of this material; and in localities where it would not be considered unsightly, it is certainly preferable in buildings on the side from which the prevailing winds and rains set in during the wet season, as it not only throws off the moisture on the outside quicker, but tends to keep the interior of the building freer from moisture than any other outer protection. Of two samples of brick taken from the same wall, built in 1790, in Recife, although not in any way protected by plaster, or lime whitewash, one appears to be quite perfect, while the other is rapidly decaying, and shows the necessity of outward protection, as a general rule, owing to the all but impossibility of obtaining, in large quantities, thoroughly well-burnt bricks.

Tiles, in Brazil, are almost invariably of the form shown in the specimens, and are made of similar material to, though where obtainable of better clay, than the bricks. When well burnt, and of a good shape, with sufficient overlap when laid on the roof, native tiles answer their purpose exceedingly well, and being thin, and invariably burnt in ovens, this process is so effectually performed, that the weather seems scarcely to affect them, either on the sea-board or in the interior. Their chief recommendation is, however, the thorough ventilation afforded by them in all buildings. Should at any time corrugated iron buildings, with roofs of similar material, become largely introduced within the tropics, it will, it is believed, be found desirable to cover these with native tiles, both for the protection of the roof, and for keeping cool the interior of the building, unless a double roof is used, 3 inches or 4 inches apart.

In Brazil, rafters are selected from the young trees of the forest, from 3 inches to 4 inches in diameter, and from 20 feet to 30 feet long; and when of proper quality of timber, these rafters answer their purpose very well and are of considerable duration.

Laths are in nearly all cases made from the sap-wood of one of the hardest and most durable timbers in Brazil, 'Imberiba.' A chisel, or axe, is introduced into the end of the stick of timber, about $\frac{3}{8}$ths of an inch from the outer edge: very little force splits it in the direction of its length, allowing the fingers and hand to be introduced, and the lath is reft off, retaining an uniform thickness, with a breadth of from 2 inches to $2\frac{1}{2}$ inches.

Permanent-way keys, cut from native timber, have, since the opening of the Pernambuco Railway in 1858, been used for renewals, and with success. The timber, being of a remarkably close nature, has not shrunk after use, as the imported keys are liable to do. With keys, as with sleepers, there is not the least necessity for creosote. In fact, with some keys kept constantly in creosote for three months, when sawn through the centre, the oil only appeared a little below the surface.

Rails are found to oxidise considerably when left near the sea-coast. It will therefore be advisable, in the construction of a line, to remove them into the interior, as soon as it is convenient to do so. When in use, in whatever locality, the motion of the trains appears to prevent any considerable amount of rust from forming. There is, however, a matter for serious consideration, as regards permanent-way rails in the tropics; and that is their tendency to flatten, or laminate, after being subject to the wear and tear of the engines and trains for a short time. This is no doubt owing to the high temperature during the greater part of the day, and the constant passage of the trains when in that state. The remedy appears to be, the substitution of steel, or steel-faced rails, and engines as light as the traffic of the line will allow. Whilst on the subject of engines, it may be as as well to mention the rapid wear of the wheel tires in the tropics, particularly on lines like the Pernambuco, with numerous curves. Where it has been found necessary to adopt steel tires, in addition to an arrangement for keeping the leading wheels wet when going round curves, there is a small pipe from each pump to the front upper side of the leading wheels, made so as to open and close at pleasure from the foot-plate. Although this arrangement answers exceedingly well, in saving the flanges of the wheel tires, as well as in causing the engine to work round any curve much easier, still this can only be looked upon as a desirable expedient in existing engines. The bogie should be used with all engines made for tropical climates, where the rails are so constantly hot and dry. The saving in the rails, as well as in the wheel tires, would be considerable, and there would be greater safety in working, as it is found that the dryness tends to make the leading wheel-flanges grip, and, when a bad joint occurs, mount the rail.

Chairs and spikes do not require any special notice, as, with the

exception of the former not being so liable to breakage, owing to the absence of frost, these need not, in any way, differ from those used in England.

About 10 miles of the Pernambuco Railway are laid with Greaves's 'pot' sleepers, as to the durability of which in the tropics there is no question, though found to be too rigid even in fine sand ballast. Had these sleepers been used on the deep banks when first formed, the usual subsidence during the rains would have caused considerable breakage, and in any case much more ballast would have been required than generally falls to the share of railways abroad when first opened. A portion of the 10 miles actually laid has, however, been considerably improved, by introducing the ordinary fish plates, with four bolts, and suspending the joints. The easiest method of doing this is by cutting away about 15 inches of the first lengths of rails, knocking out all the keys, and then drawing the rails in succession 15 inches back, by which the joints are brought into the centre betwixt the joint and the next intermediate sleeper, the 'pots' remaining undisturbed. The fish plates are then put on. The 15-inch pieces are always kept at hand to be introduced to allow for the passage of the trains. This work was done by the piece, and cost 1*d.* per pair of joints.

The carriages of the Pernambuco Railway are made with a strong wrought-iron under frame. The body is of teak, the inside lining is also of this material; the outside panels are of 'papier mâché.' After six years' hard work and exposure to sun and rain, these carriages are in excellent preservation. The material employed for the outside panels has proved in the highest degree suitable for the tropics, and will probably be generally adopted when its good properties are known. But whether 'papier mâché' or timber is used, the panels should be well painted and varnished, or the sun will not fail to destroy them. The first carriages sent out to Bombay for the Great Indian Peninsula Railway, with panels of varnished teak, split after being exposed to the sun for a short time, whereas in the 'papier mâché' panels on the Pernambuco Railway, there is not a crack in any of them after six years' wear and exposure.

The railway wagons for the Pernambuco Railway were constructed in Brazil, the iron work having been sent from England; the under frames are made of native timber, and the body of white or yellow pine. The great heat of the sun is found to dry up and cause the sides, and particularly the roofs, of these wagons to become leaky. Zinc has therefore been used as an outer covering for the roofs, and will no doubt answer. For the tropics, the most serviceable covered goods wagon will be found to be one constructed with an iron underframe and a light galvanised iron body.

In conclusion, there is no doubt that the subject of the Decay of

Materials in Tropical Climates, and its prevention, is but little known, though deserving of being thoroughly investigated. It is hardly to be expected, that any one individual will be found to possess the information necessary to treat upon this subject with reference to all tropical countries; but it is to be hoped that some Member will take the trouble to compile the results obtainable from all reliable sources, and produce a work which will not fail to be acceptable to all who take any interest in these countries, and particularly India.

APPENDIX.

A.

List of Brazilian Timbers suitable for and now being used as sleepers on the Pernambuco Railway:—Sicupira; Oiticica; Almesca Brava; Gararoba; Gulandin; Paó Santo; Angelim Amargozo; Sapucaia de Pilão; Amarello Vinhatico; Maçaranduba Preta. The present price of the above, for sleepers, 10 inches by 5 inches, by 9 feet, delivered at stations on the line, is 2*s*. 7*d*. each.

B.

List of Brazilian Timbers suitable for general purposes in permanent structures:—Sicupira Assú; Sicupira Meirim or Verdadeiro; Sicupira Acari; Oiticica; Gararoba; Paó Santo; Sapucaia de Pilão; Sapucarana; Massaranduba; Imberiba; Paó Ferro; Paó d'Arco; Barabu. These cost 1*s*. per cubic foot, and are of great durability, and resist the white ant excepting in the sapwood.

The following are as durable as the foregoing, and resist the white ant even in the sapwood on account of their bitterness:—Angelim Amargozo; Araroba; Pitia (Gararoba) and Pitia (Marfin). These also cost 1*s*. per cubic foot. Cocão, Bordão de Velha and Arueira do Sertão, are very durable, and resist the white ant; but are not to be found of any great dimensions. These likewise cost 1*s*. per cubic foot, as do Parahiba and Cedro, which are very suitable for boarding, their strong smell and their great bitterness repelling the white ant. The price of Louro Cheiroso and Louro Ti is the same. These are of a porous description, fit for doors and shutters. The Cheiroso repels the white ant, owing to its smell; the heart of the Ti is very strong and durable, resisting the white ant. For Amarello Vinhatico and Amarello Verdadeiro, the cost is 1*s*. 1½*d*. per foot. They are of great durability, and are extensively used in cabinet work.

C.

Table of Specific Gravities of Brazilian Timber suitable for Shipbuilding.

Name.	Lbs. per cubic foot.	Uses.
Louro	37	Yards, masts, &c.
Jequitiba	44	Do. do.
Amarello	46	Planks for above and below water.
Putumugú	48	Do. do. do.
Paó d Oleo (Vermelho) .	56	Yards, masts, &c.
Olandim	57	Bowsprits, topmasts, gunwales, &c.
Sicupira Meirim . . .	59	Useful for every part of a vessel.
Paó Roxo	63	Keels, sternposts, ribs, &c.
Paó d'Arco. . . .	66	Do. do. do.
Peguim	64	Deck beams, &c.
Sapucaia	73	Keels, ribs, &c.
Jetahy (Amarello) . .	66	Gunwales, &c.
Massaranduba . . .	68	Beams, posts, &c.

No. 1,125.—"On the Decay of Materials in Tropical Climates, and the methods employed for arresting and preventing it."[1] By William Jerry Walker Heath, Assoc. Inst. C.E.

It is proposed in this Paper to allude to those materials which are most used in the construction of permanent buildings, and such as have come under the immediate notice of the Author, during a residence in Ceylon extending over a period of seven years.

The habitations of the lower class of natives are constructed of a rude framework of stout bamboos, the sides and roof formed of reeds, and closed in with the interwoven leaves of the cocoa-nut palm (Cadjans), laid on after the manner of weather-boarding, and secured to the reeds by pieces of coir-string, formed of the twisted fibres of the husk of the cocoa-nut. In the ordinary course, the cadjans require renewing every year; but these leaves may be made to last two or even three years by washing them over with the slimy juice of the 'bellie' (a native fruit), which when dry resembles copal varnish, and acts, to a considerable extent, as a preservative against the weather.

The framework of the huts, built of 'wattle and dab,' is made of roughly-squared jungle trees, morticed and tenoned with some care, and secured by trenails. Small twigs are tied with coir, in parallel rows, vertically and horizontally, both on the inner and the outer sides of the framing. The space between is filled with clay and sand, well kneaded, and when nearly dry, both the inside and the outside of the hut are covered with the same material. It is then plastered over with earth, which has been thrown up by white ants, after being mixed with a powerful binding substance (produced by the ants themselves), and through which the rain and moisture cannot penetrate. This will hold the walls together, when the entire framework and the wattles have been eaten, or have become decayed.

The material of which the walls of the superior houses and other buildings is built is called 'cabook,' a soft kind of rock, found in most parts of Ceylon, at a few feet below the surface of the ground. A large square pit is excavated, and the cabook laid bare, when it is quarried, by means of a pickaxe, into blocks of a convenient size for transport, or of the size which will best suit the building for which it is intended. Cabook has the appearance of a

[1] The discussion upon this and the preceding Paper occupied portions of two evenings, but an abstract of the whole is given consecutively.

coarse sponge, the material of the sponge resembling red iron ore, and the insterstices being filled with soft clay of a yellowish or brown colour. The block should be exposed to the rain before being used, so as to allow some of the clay to be washed out, as then a better face for the mortar to adhere to is formed. Buildings of cabook require protection from the weather, but if covered with a thin coating of lime-plaster, they will stand for many years. When removing some old Dutch buildings, the cabook did not appear to have deteriorated in quality.

Hard kinds of stone are not much used for buildings, on account of the expense of working. Rubble masonry is sometimes employed, but it is not approved, owing to the difficulty of obtaining even beds and good bond. The cathedral church of St. Thomas, near Colombo, is an instance of the successful adoption of rubble masonry. It has now been built upwards of ten years, and is in a good state of preservation, having the appearance of having been recently built.

Bricks are so badly burnt, and the clay is so badly pugged, that brickwork will often, after a shower of rain, scarcely bear the least weight without crushing. Although used in some instances with its surface exposed to the influence of the weather, it will undoubtedly exist for a much longer time, if well plastered with lime-mortar. Two or three coats of boiled linseed-oil will preserve brickwork without hiding it, but the expense prevents its general adoption. A coating of coal tar, applied when the day is fine, and the brickwork dry and hot, is also a good preservative; but it cannot, on account of its unsightly appearance, be often employed. Brickwork in exposed situations and unprotected will perish very rapidly. The softer bricks will be hollowed out, leaving the mortar joints projecting; and in damp places the bricks will in less than a month be covered with lichens.

The lime generally used is made by calcining white coral, of which there is an abundant supply on the coast, easily obtained. Timber is the fuel used in converting it. The lime comes from the kiln in a fine white powder, and is in that state ready for immediate use, by mixing it with twice its own bulk of sand and water; but it sets so rapidly, that the bricks have to be kept quite wet, and water has to be continually added, to prevent its setting before the bricks are truly placed. In the Public Works Department, the lime is placed in a tank, and kept under water for two days before being used; this makes it longer in setting, but it is more easily worked, and eventually makes better work. In fact by the first plan it often simply dries, and is very friable; but in the latter case it sets equal to the best blue lias lime. In using this coral lime for plastering, it is better not to slack it for two days, as mentioned, it then presents a harder face, and will bear a high

polish, almost like white marble. A short time ago the exterior of public buildings was painted, but this practice has been discontinued as it answered no good end, and after a few months generally presented a bad appearance.

Timber, well seasoned, and built so as to have free ventilation, will, if white ants be kept away, endure for many years, though not for so long a time as in England. The best wood for general use is Moulmein teak. It begins to fail in about twenty-five years, but the decay is very slow, for after a hundred years, it is still in tolerably good condition. It would appear, that woodwork lasts longest when no precautions are taken to preserve it. In exposed situations, and where it is subject to the attacks of the white ant, it is best preserved by a dressing of Stockholm tar, which is easily applied, and which, owing to the heat, is so limp as to insinuate itself into all small sun-cracks or fissures. Several substances, such as corrosive sublimate, have been used with success; but the cost precludes their use, except in cases where a second coating of tar cannot be easily applied. In sea-water, timber is speedily attacked by worms. The piles of the jetties in Colombo Harbour, which are mostly of satinwood, and about 14 inches in diameter, are so pierced in the course of twelve months as to require renewal. There is also a very small worm in the fresh-water lakes and canals, which infests the bottoms of boats, &c., notwithstanding the timber may be painted, oiled, or tarred. Creosoted timber is not attacked by white ants, but the black coating, if exposed, renders it so heat-absorbing, that it is apt to split, and, unless thoroughly impregnated with the creosote, a road is opened to the inside, and the ants will soon destroy all that part which is unprotected. Timber near the sea does not warp, or split so much as when removed inland; the changes from wet to dry not being so sudden in the former situation.

Iron, exposed to the influence of the varying weather, speedily oxidises; but not to so great an extent in the same time as in England. Painting, if applied at home, will for a time preserve it; but if applied in Ceylon it is not so effectual. Oil applied hot is a good preventive; but when applied cold, or in the same way as paint, it is of little avail, because the iron oxidises under the paint or oil. Coal tar is by far the best covering, applied either cold or hot, before or even after oxidising has commenced. In the first condition it prevents, and in the latter arrests, nearly all tendency to rust. The heat, which contracts oil, or paint, causing minute fissures that admit moisture, in the case of tar has the effect of causing any small parts not properly covered in the operation of tarring to be flushed over with a thin coating. The most valuable timber in Ceylon is quickly decayed by contact with unprepared iron; so that screw-nails, or spikes, unless well-greased or tarred,

may, in an incredibly short time, be easily drawn out, the wood surrounding them being quite rotten.

Ordinary galvanized sheet-iron does not last many years, except it be protected with good red-lead paint, frequently renewed.

Lead-piping that has been four years in the island is still nearly as bright as when the pipes were first drawn. Brass oxidizes, and becomes very brittle, in a much shorter time than in England. Lacquer is the only preventive applied for the first defect, and for the second, the brass is heated nearly to a red heat, and then dipped in cold water. Zinc is a most durable material. It will last for many years with little or no apparent decay. Glass exfoliates in a short time. It requires constant care to preserve the lenses of optical instruments. Tripoli powder on the hand will remove the exfoliation.

Paper is easily affected by the moisture of the atmosphere. It loses its size, the surface becomes rough, and in a short time is so absorbent, as to render it impossible either to write or to draw upon it. It requires to be kept in air-tight cases, and only so much of it should be exposed as may be required for immediate use. Leather, unless well 'dubbinged,' becomes so brittle, as to break short off like a piece of wood. Gutta-percha, in about twelve months, is so brittle as to break like glass, but more easily; and after about three years, it may be reduced to a powder in a mortar. Occasional immersions in hot water will arrest this decay, but articles the shape of which would suffer by the heat must be left to their fate.

Mr. Berkley remarked, that he had sent out to Bombay both creosoted and kyanised sleepers: native jungle-wood had also been used. He regretted he could not give the details of the results of these several experiments. He could, however, state this general fact, which was of much practical value: the resident Engineer of the Great Indian Peninsula Railway, after an experience of thirteen years in India, was now replacing large numbers of sleepers which had failed, with teak and iron sleepers. Attempts were made, in the first instance, to preserve the native wood by the usual processes; but, he believed in consequence of the wood being so hard and close-grained, it was impossible to impregnate it sufficiently with the preservative material.

Keys were a matter of considerable difficulty in warm and variable climates. It had been reported to him, that the wooden keys (which were, he feared, perhaps not made with the utmost care,) dropped out in great numbers, and he was now giving his attention to the introduction of some other kind of key, which would answer the purpose better than the wooden ones.

With respect to the preservation of iron, the result of his experience was, that whether for rails or bridge-work, iron should be thoroughly cleaned and dried by heat, and be then dipped into hot linseed oil. In the first instance, iron-work was sent out to Bombay not so treated, and the oxidation was excessive; but since that plan had been adopted, the oxidation was prevented, and the rails and other iron-work remained in a perfect state.

On the subject of rolling stock, it was stated in Mr. Mann's Paper, that the carriages on the Great Indian Peninsula Railway were sent out with teak panels. If that were so, it was at a very early period, and before he had much voice in the matter. For some years past, the carriages had been sent out with 'papier mâché' panels; but notwithstanding his own opinion that it was the best material for the purpose, the locomotive superintendent, who ought to know better than himself, had expressed a desire that the panels should be of teak, and not of 'papier mâché.'

Mr. Hawkshaw, Past-President, said, he had spent three years of his early life in a tropical climate, close to the equator, and had had some experience with regard to what timber would do in a country which Humboldt declared to be the hottest part of the world. He had also had many years' experience of Indian and of foreign railways, and of the duration of the rolling stock, sleepers, and iron-work sent out to those countries.

He would say, with regard to timber generally, that being an organic substance, it was impossible for any one to predicate what it would sustain under the varying circumstances in which it was employed in those countries, or, indeed, elsewhere. For instance, he had known yellow pine, which, according to the statements of

joiners, was not a good wood, last in railway-sleepers for twenty-five years, and at the end of that period it was as sound as any of the specimens that had been exhibited. But in other cases, yellow pine had decayed in five years or six years. Dealing with timber was something like dealing with the human constitution: it was impossible to tell what or how many incipient seeds of decay it might contain.

He was acquainted with some of the woods exhibited. He had seen some of these hard woods which, under certain circumstances, had lasted as long as the piles from the Recife jetty; under other circumstances, from causes which he could not explain, the same descriptions of wood had gone to decay after a very short period. Among the large masses of timber that were required in the construction of railways in tropical climates, if native timber were used, it was bought without knowledge of the soil in which it was grown, or at what period of the year it was cut. Of course every proper precaution ought to be taken in the selection of the wood, but it was one of those subjects on which it was not safe to draw such large general conclusions as had been done in Mr. Mann's Paper.

With regard to the question of sleepers—whether half round or square—he could not understand on what principle the former should be more durable than the latter.

Mr. MANN said, the half-round sleepers were more durable than those of the square form, because, independently of the half-round shape allowing of better drainage, the wood used was of a closer grain than the square sleepers.

Mr. HAWKSHAW, Past-President, observed, with respect to the preservation of iron-work, that he could not agree with the suggestion, that galvanizing should be substituted for every other process. He had used galvanized iron, and he was willing to confess, in some cases unfortunately, and therefore, he had the less hesitation in stating his opinion of it. He had put up roofs of galvanized iron, and found them decay more quickly than other roofs; in fact, if to that material acid were applied, and carbon, as was easily done in smoky situations, it was converted into a good galvanic battery: roofs in towns were destroyed in that way. In addition to this, the process of galvanizing rendered the iron brittle; therefore he did not recommend that iron about to be sent to India should always be subjected to that process, in preference to oiling and painting. The other suggestions were very proper. The iron should be well cleaned and dried before painting, for if wet or rusted iron was covered with any kind of coating, oxidation was certain to take place. No doubt, in tropical climates, there was a difficulty in making durable works, either of iron or wood. He had tried almost every material for

sleepers—native woods, and woods of this country, and Baltic timber creosoted and not creosoted, and he confessed he had not derived much better results from one than from another; and he had been driven to the conclusion, that in the tropics iron was pretty nearly the only thing that could be employed for sleepers with anything like certainty as to the results. He quite agreed in the opinion that iron made a very rigid permanent way. Rigid ways were not liked in this country, but sheer necessity brought him to the conclusion, that a durable road could not be made in tropical climates except by the use of iron. Iron sleepers, he believed, had been rejected by many Engineers. He believed he was the first to use the iron-pot sleepers in England, and he found them rigid and did not like them; but necessity had obliged him to use them in tropical climates; and he was afraid, notwithstanding all the care in selecting native woods, creosoting foreign woods, and taking every other precaution, it would be necessary to use iron very extensively in tropical climates. When in Egypt, he saw the line constructed by the late Mr. Robert Stephenson with Greaves' cast-iron pot sleepers, which, after great consideration, Mr. Stephenson adopted as the best compromise he could make. Those sleepers had been laid, he believed, more than ten years, and the line was a good and substantial one, and the sleepers stood well. Iron sleepers broke only when not made strong enough; but it would be easy to make iron sleepers that would not break; and where the speed was not required to be more than 25 miles or 30 miles per hour, he saw no reason why iron sleepers should not be used. Whether, ultimately, a better material would be discovered, he could not tell. With regard to the laminating of the rails, he could not see what the temperature of the climate had to do with it. Whether the temperature were 100° or 50°, could make little difference; nor did he think that the use of steel could be more beneficial, or necessary, in a tropical climate than in this country. Steel was better than iron anywhere; but there was no reason why it should be used in the tropics more than here.

Upon one subject there appeared to be a singular confusion of ideas. That was the statement, and similar opinions had been expressed upon other occasions, that the cross-girders should rest upon, and not be suspended from a main girder; but the fact was, that cross-girders which were said to rest were suspended. It did not seem to be understood, that when a cross-girder was made to rest upon the flange of a main girder, the flange on which it rested was suspended from the vertical web by rivets.

Mr. James Brunlees said, during a short stay he had made in the Brazils, he had an opportunity of observing the different qualities of timber, some of which he recognised in the specimens exhibited; but he had not had much experience, as to the durability

or otherwise of these woods. On 5 miles of the San Paulo Railway, he had laid sleepers of native timber; and, by the last reports, he was informed, that after having been in use two years, they were decaying very rapidly. On the other portions of the line he had used cast-iron pot sleepers, which, like all the other iron-work he sent out, were boiled in a preparation of tar and asphalte, before being shipped, and he found that treatment was a good preservative against rust. He had used the same kind of preparation for iron for about twelve years; and he could refer to its beneficial effects in the case of the Morecambe Bay viaducts. He had had no complaints of the breakage of pot-sleepers, nor had he received any complaints of the road itself, which he attributed to the circumstance of the rails having been well fished. A different state of things appeared to have existed on the Pernambuco Railway, where the rails had not been fished in the first instance, and where, therefore, the road was not so effective. He certainly should not lay down the same sort of road in this country for high speeds; but he thought in tropical climates there was no better material than iron, either for the permanent way or for bridges, and he believed that was the material Engineers must mainly depend upon.

Mr. Bruce thought, the Institution had reason to be indebted to the Authors for the great care with which they had collected the facts, and for the methodical manner in which they had laid them before the Meeting. It struck him that there was a weakness in the argument against resting the cross-girders upon the lower flange, the general question of which he would not now discuss; but when girders were suspended by rivets, as was virtually done when the cross-girders rested on the lower flange, it must be recollected that this strain, which was said not to have been calculated, must ultimately come upon those new rivets in the case of the suspended girders.

Passing to the question of sleepers, he was struck with the similarity of the experience which had been gained in South America, with that which had been gained by Engineers in India. There were doubtless many native woods suitable for sleepers and for other purposes, if there was only time to get them, and roads along which to carry them; but in the first instance, if a wood suitable for sleepers was found, there were no roads for getting them to the works, and the only thing that could be done was to send out from Europe either memel creosoted sleepers, which were known to stand, or cast-iron sleepers which were also known to be very efficient. He believed, ultimately, when railways were more extensively opened than at present, the renewals might be made with native timber, because there would be more ready access to the forests; and because it would not be required in such

large quantities as was the case at first, when contractors were forced to buy timber where they could; but each supply might be obtained as required for the maintenance without any undue pressure. He thought the use of the bogie engine, as recommended in Mr. Mann's Paper, would be attended with great advantages, as it enabled trains to be run over somewhat inferior roads with greater ease and safety than could be done without that very useful appliance.

Mr. HAWKSHAW, Past-President, remarked, that the assumption that creosoted memel sleepers would stand in these climates must not be adopted as correct.

Mr. H. P. BURT said he had been informed, that the sleepers first sent out to Pernambuco were of an inferior quality of white wood, and not well prepared. The best evidence he could give of the general estimation in which creosoted sleepers were still held, was the fact, that he had contracts to supply upwards of 450,000 creosoted sleepers in various parts of the world. He had recently been in communication with Sir Macdonald Stephenson on the subject of the preservation of timber. The specifications of nearly all the Engineers were for the wood to be creosoted to the extent of 10 lbs. of creosote per cubic foot; but it was found, even with that large quantity, that the centres of the sleepers were not impregnated with the fluid; and some of the failures were no doubt attributable to that fact. Sir Macdonald Stephenson had suggested, as a means of obviating that defect, the boring of two holes 1 inch in diameter through each sleeper longitudinally, and impregnating up to 12 lbs., or 14 lbs. per cubic foot. By that means the creosote would be sent all through the sleeper. The boring by hand would be an expensive operation, but he had thought of erecting machinery by which he hoped to effect it at a comparatively small increased cost, and to accomplish the object in view.

Mr. A. M. RENDEL, speaking from facts which had been communicated to him rather than from his own personal experience, thought there was no cause for supposing that the deterioration of materials was so excessively rapid in tropical climates. He considered that good materials would last nearly as long as in temperate latitudes. There were as good sleepers in India as in this country, but if mere jungle-wood was used, it would perish in a very short time. Bricks also, if made properly, turned out well; but if made after the manner of the country, were extremely perishable.

Mr. TURNBULL could corroborate to a certain extent what had just been stated. On the East Indian Railway—of more than 1,000 miles in length—the greater portion was laid with Saul-wood sleepers; a considerable portion with creosoted fir; and a small length with cast-iron sleepers. Although there were various kinds

of woods in India suitable for the purpose, such as Sissoo, Assoon, and others, there was difficulty in getting large quantities of any kind, except Saul, and that wood, when of good quality, was very durable; but at first there was a great and sudden demand for sleepers, and many young Saul trees were used, as a matter of necessity, with much sap-wood in them, which perished rapidly; otherwise Saul wood was very durable, when cut out of large timber and well seasoned. In some instances, he had known Saul-wood sleepers to perish in two years; but he had lately taken up sleepers near Calcutta, which were serviceable after having been in use eleven years. At other parts of the line there were creosoted fir sleepers which had been laid ten years and were still serviceable, whilst others had decayed in less than three years. He had found, that unless the creosoting was thoroughly done, and good timber used, fir sleepers were perishable. Teak was perhaps the best of all Indian woods, but its present scarcity had brought the price to about equal to 15*s.* per sleeper, which precluded its use for that purpose. Saul sleepers and creosoted fir sleepers were about half that price. With regard to iron sleepers, he had used flat ones at first, but without success. Greaves' 'bowl' sleepers were more successful, but as yet the experience of them was not sufficient to warrant a decided opinion. There had been a good deal of breakage in some places, in one year as much as 20 per cent. was reported; but as had been observed, the breakage could be obviated by making the sleepers stronger. He had only laid a comparatively small number of these iron sleepers. He thought, on the whole, it was desirable to introduce these or some kind of iron sleeper, not universally, but partially, in India, from the difficulty of getting large supplies of wooden sleepers, and from the uncertainty of the quality of the timber. A length of one mile near Howrah, had been laid on a plan of his own, as an experiment. It consisted merely of a bridge rail bolted to a continuous longitudinal bearing of plate iron, with a teak wood board between the rail and the plate iron; it had been in use for about four years, and seemed to answer tolerably well, except having been made too weak at the joints of the longitudinal bearing.

So many miles of railway in India had already been laid with chairs and wooden cross-sleepers, that a change to iron sleepers would be too expensive, but should be considered on new lines. As regarded creosoting wood in India, it was a costly process, owing to the difficulty and expense of conveying creosote from England; iron tanks were necessary to hold the oil when on board ship, and being unsaleable in India, added to the expense. The native woods were generally too hard for penetration: the creosote did not penetrate Saul wood more than $\frac{1}{8}$th of an inch.

The earth oil, or Arracan oil, seemed as good as creosote, but the same objection applied, as to the difficulty of conveyance and the cost. It was brought from Moulmein and Rangoon generally in leathern bottles, or skins. The price was about 6*d.* a gallon.

General Sir ANDREW WAUGH regretted he had not come prepared with notes of his experience in India. He had been a short time only in Ceylon, but had visited both Colombo and Galle, and could corroborate much that was stated in Mr. Heath's Paper. The decay in the materials of buildings arose obviously from the alternate effects of extreme heat and extreme moisture, but principally, he thought, from the use of bad materials. India presented great varieties of climate, which, in the upper districts, differed much from that of Ceylon. And the Hindoos there had brick and stone buildings of great antiquity; dating, in fact, anterior to the historic periods.[1] The masonry of some of the temples and forts was exceedingly strong, and was difficult to destroy when it was requisite to blow the forts down.

With regard to wood, the great difficulty in India was to get it seasoned. Such was the pressing demand for wood, that it was used without seasoning, and there were no capitalists in the trade who could afford to keep stores of wood for seasoning purposes. It was almost impossible to get a piece of well-seasoned timber for a chair or a table. He could fully corroborate what had been stated by Mr. Turnbull with regard to Saul wood. It was a very hard wood, of great strength, the product of the Shorea Robusta, which grew in great abundance in the central forests, as well as along the skirts of the Himalayas; but though it was a wood of excellent quality for all purposes of construction, there was, no doubt, of late years, a great difficulty in obtaining a sufficient supply of it, well seasoned, for sleepers. Teak was a wood famous all over the world, but it was getting scarce, from the trees being destroyed so rapidly without any equivalent reproduction. There was a peculiarity about that tree; the seeds did not sow themselves readily like Saul, and were floated away by the rains. There were two kinds of teak wood in India, that in the province of Burmah grew to a large size, and was much used in shipbuilding. The same kind of timber grown in a drier range and in rocky parts, as in the Vindhya ranges in central India became as hard as ebony,

[1] While carrying on the Great Triangulation through the Turai (damp forest lands), near the feet of the Himalayas, Sir Andrew Waugh fixed several of the principal stations on the ruins of forts of such antiquity, that forest trees of the largest size were growing in the forts, the building of which was attributed to Bimseu, a demigod of Hindoo mythology. The bricks in these forts, which were used to build the towers for the Triangulation, were so excellent, that their arrises remained quite sharp after many hundred years; and the mark of three fingers on the face of each brick were quite distinct, being either a trade mark, or, more probably, a sign of the Triune Deity.—A. W.

or iron-wood, but was of small scantling and of crooked form, nevertheless it was an excellent wood if it could be obtained in sufficient abundance and size for sleepers, or for other purposes requiring strong and durable timber.

Colonel SALE remarked, that the results generally mentioned were such as he could corroborate from his own experience; that timber sent from this country to a tropical climate should be prepared beforehand, and that perhaps creosoting was the best method. Simply paying over native woods with coal-tar, he had found to act well as a preservative. In using timber for building purposes, it was necessary to provide for the ventilation of the ends of the timbers, by which means it would last considerably longer, than if the ends were let into the work without the admission of air. Saul was, no doubt, the best quality of wood in Bengal and the north-west provinces of India; teak was both scarce and expensive there. In fact it might be said, Saul was the timber generally used in the works of the public departments in those provinces.[1] The results mentioned in the first Paper, as occurring in Brazil, he had observed very much elsewhere.

Mr. C. H. GREGORY, V. P., thought they were much indebted to Mr. Heath, as a young member of the Institution and of the profession, for the practical observation which he had brought to bear on the subject under consideration. It was curious that two Papers arriving so nearly at the same time from countries so far apart as Pernambuco and Ceylon should agree so nearly in their conclusions; and he thought that this general but independent agreement between Mr. Mann and Mr. Heath made their Papers so much the more valuable. The most important difference between them seemed to be as to the use of galvanized iron, of which Mr. Mann gave a favourable opinion, while Mr. Heath, speaking, as it seemed, from experience, thought that galvanizing was not sufficient without additional protection in such a climate as that of Ceylon. One statement in Mr. Heath's Paper was at first sight striking; viz., that the loss of weight in iron from oxidation had been observed to be less in Ceylon than in England during an equal period of time. In confirmation of the correctness of that statement he might mention that, while the works of the Ceylon Railway were suspended, a quantity of rails were lying for many months in Ceylon unused, and rails of a similar nature, manufactured at the same place, were lying in South Wales unused: he expected that the loss of weight would have been greater in the rails in Ceylon, instead of which the reverse had been found to be the case. He considered Mr. Mann's Paper as very interesting, because it brought before them the results of experience of some

[1] Teak is procured in the central provinces, and on the Bombay side.—T. H. S.

years in a country in which the Engineers of the Railways had been the pioneers of public works, and from the independent and careful nature of Mr. Mann's observations, all he had stated was entitled to great respect and consideration. In reference to the use of timber in tropical climates, it had often been discussed, whether the soft European woods artificially prepared were to be preferred to native woods. He had been surprised at hearing it stated, by a gentleman of large experience in works in tropical climates, that the deterioration of such materials in tropical climates was no greater than in England. He imagined that where there was great heat, accompanied by excessive moisture, the deteriorating effect, upon wood especially, must be much greater than it was in this climate, and that this effect would be most serious on soft woods; and while in the first instance, from the supply of material being uncertain, and unequal to the demand, it might be desirable to import European timber artificially prepared, he could not but agree with Mr. Mann, that in most tropical climates where timber was plentiful, and certainly in the country to which his Paper referred, after the character of the native woods was known, and their selection and supply properly organized, they might be used with great advantage, while Mr. Mann had shown that in Pernambuco this was now done at half the cost of European timber artificially prepared.

It should be remembered that the natural decay of timber was only one portion of the question; for where timber was exposed to great moisture and great heat, the alternate swelling and shrinking must produce shakes in the timber, while the working of rails, chairs and fastenings must produce mechanical deterioration, which would naturally be less in the hard woods of the tropics than in the softer woods of Europe. They had on the table specimens of the woods of Brazil, which in an unprepared state had lasted undecayed for 250 years: even if it could be proved that creosoted soft wood would remain as long undecayed, the durability arising from hardness would still be in favour of the native wood.

In alluding to iron bridges, Mr. Mann differed from some Engineers in condemning entirely the use of suspended cross girders. Those bridges to which Mr. Mann alluded were sent out by him (Mr. Gregory), as consulting Engineer of the Pernambuco Railway, and therefore he felt he was to some extent upon his defence. It was sometimes convenient to suspend the cross-girders, and when these were properly arranged and the bolts sufficiently strong and well secured, he submitted that there was no radical departure from the rules of good construction. With regard to Mr. Mann's proposed substitution of steel for wrought iron in the bracings of bridges, he believed that the adequate use of coal-tar would be a sufficient protection for wrought-iron braces, and he

thought that the specimen exhibited of a brace which had suffered from the effects of the weather, might be matched in this country in many structures still considered to be in a permanent and sound condition.

He was not prepared to adopt Mr. Mann's views in ascribing to the heat of the climate the large amount of wear which had been observed in rails and tires on the Pernambuco Railway, and he thought they must seek for other causes to account for it. When this railway was projected, the fishing of joints was not so generally adopted as it had since been, and it was not proposed, in the first instance, to use fishes, and they had only been applied after a portion of the line was opened for traffic. Again, from atmospheric alternations, and from the difficulty of obtaining perfect work in a country where railway operations were entirely new, from the nature of the ballast, from the deterioration of sleepers, and from other causes, the permanent way was not for a long time, even if it was now, in the good state attainable on English railways. There were also several considerable curves on the line. He thought the combination of those circumstances sufficient to account for a much greater wear than was usual in England, without the necessity for a theory which had rather startled him in Mr. Mann's very useful Paper.

Mr. C. B. Lane said, as the result of twelve years' experience of Brazilian railways, he agreed generally with the views expressed by Mr. Mann with regard to the preservation of materials; and some of the results stated in the Paper were very satisfactory to him, inasmuch as they bore out reports he had made from time to time to the Brazilian Government on these questions. He alluded more particularly to sleepers. When he first had to deal with this question in Brazil, there was no time to make botanical investigations, nor was there the knowledge available to enable him to fix upon really fit material, the product of the country. He felt it therefore to be his duty to recommend the employment of such material as practical experience in other intertropical countries had shown to be good, rather than the adoption of what had not this test in its favour. And for this reason, where timber was employed, he had recommended that of the north of Europe creosoted. He had also recommended the 'iron pot' sleepers, having had the high authority of the late Mr. Robert Stephenson in their favour, and having also had the opportunity himself of judging of their value on the Mauá Line at Rio de Janeiro. That line had now been about eleven years in operation, and he had recently seen some statistics of its maintenance, from which it appeared that the renewals of the pot-sleepers were very small, in fact practically almost nothing. He had heard of their failure on some Indian lines, but he thought it must be owing to their not

being thick enough along the centre line of the pot: he would recommend their being cast with an internal ridge in that direction, somewhat similar to the ridge along the vertebral line of the shell of a turtle.

He agreed with Mr. Gregory, that the time might arrive, when it would be desirable for English Engineers in Brazil to fell timber and prepare it, either by shed-drying or other means, so as to get a really good native sleeper. If that could be done at the price mentioned by Mr. Mann, in comparison with the cost of creosoted timber sent from this country, it was obvious to those acquainted with the financial position of Brazilian railways, that it would be a matter of the greatest importance to the railway system in that country.

He was glad to hear the remarks made by Mr. Gregory in favour of 'fish-joints,' and that he partly attributed the injury to the rails of the Pernambuco Railway to the absence of 'fish-joints' in the earlier stages of the line, as it had cost him (Mr. Lane) some pains to get them introduced into that country.

With respect to the carriages which were sent out about seven or eight years ago, now referred to by Mr. Mann, Mr. C. B. Lane had at that time made a most favourable report of them to the Government, and would now repeat that he never saw carriages more commodious or better designed for the peculiarities of the climate and the country.

With regard to the white ants, he did not think there need be much apprehension of their ravages upon railway sleepers when in use. He had seen many old timber structures in that country unaffected by them, and, so far as his experience and observation went, he thought timber of good quality, which was subject to frequent shaking or vibration, was tolerably safe from their depredations.

He could confirm what had been stated as to bricks, both at Pernambuco and in other parts of Brazil. At Rio de Janeiro he had seen buildings comparatively new, which looked like honeycombs, the mortar joints standing out, and the bricks eaten away from half an inch to an inch and a half; and yet that mortar was made in the most careless way, of shell-lime and sea-sand, or road washings mixed with a material called 'barro,' which abounded amongst the decomposed granites of the district, and which had considerable hydraulic properties, though very inferior to the hydraulic limes of this country. In Mr. Mann's Paper the statement about the iron bridges was only correct in so far as it related to insistent bridges. The earliest iron bridge in that part of South America, or so far as he knew in Brazil, was the suspension-bridge over the river Capibaribe at Caxanga, which carried the most important of the provincial roads. He had frequently tra-

velled over the bridge, and regretted not being able to supply any minute details of its dimensions or construction, further than to say that the roadway was suspended from wire ropes, and the bridge in its appearance and in some of its details resembled the suspension-bridges over the Seine at Paris. That bridge was erected about twenty years ago from the designs of a very able Engineer, a Frenchman named Vauthier, who at that time held the position of Engineer-in-chief to the province of Pernambuco. He felt sure that all the Members would concur with him, that on a question of priority M. Vauthier's name should occupy its proper place in the annals of the Institution.

Mr. ALFRED DE MORNAY stated, that he had been Assistant Engineer to Mr. Louis Leger Vauthier, and had made the working drawings during the erection of the suspension-bridge at Caxanga in 1844; of which, speaking entirely from memory, he would give a brief description, as it was the first bridge of that kind erected in Brazil. Mr. Vauthier was a French Engineer of considerable talent, and, at the time he designed that bridge, had not long been engaged by the Brazilian Government as Engineer-in-chief to the province of Pernambuco. The bridge was situated on one of the main roads of the province, about 9 miles from the city of Pernambuco, in a north-westerly direction; it crossed the River Capibaribe at the village of Caxanga. The roadway, which was suspended from a pair of wire ropes on each side of the bridge, by means of vertical suspension-rods, was about 100 feet long and about 20 feet wide, constructed of the hard wood of the country, and was formed simply of cross-sleepers, placed at the same distances apart as the suspension-rods, and covered with rough planks. The ends of the cross-sleepers rested upon two longitudinal timbers, through which the suspension-rods were also carried. The ropes were constructed of a mass of iron wires, simply laid together and bound round at intervals to keep them in position. Each pair of ropes was connected together by a lacing of wire at each of the suspension-rods, which arrangement served to keep the rods from slipping down the rope. Each rope was composed of four lengths, so that there were in all eight separate ropes —two on each side of the bridge passing over the pillars, and two at each end of the bridge passing under massive stone buttresses.[1] The ends of the side ropes, after pasing over the pillars or rocking-standards, were looped, and the ends of the ropes that passed under the buttresses were divided into two, and each end looped also, and then all were connected together by means of wrought-iron straps and blocking pieces, thus becoming in effect two end-

[1] The double ropes which passed under the stone buttresses might be bound together into a single rope.—A. DE M.

less ropes passing all round the bridge. The rocking standards were of cast-iron, made in three pieces. The rocking-base was a segment of a cylinder, resting upon an iron plate; the shaft was made taper at both ends, and cruciform in section, and the capitals served as a saddle for the ropes to rest upon. Four long wrought-iron bolts connected the top piece of the standard with the four corners of the rocking-base, and served as diagonal braces to give greater strength to the light cast-iron shaft. The suspension-rods were of wrought iron, and were placed between the ropes, and attached to strong wrought-iron plates formed to embrace the two ropes. The whole of the work of the bridge, including the cast-iron standards, was executed in the country. The wire of which the ropes were composed was purchased in England. The wire ropes were still sound, as well as the principal parts of cast and wrought iron. The bridge was estimated to cost 40 contos of reis (about £4,500), and its actual cost was between £5,000 and £6,000.

Mr. Russel Aitken believed, that the rigidity of the 'pot' sleepers was due not to the fact of their being made of cast iron, but mainly to the imperfect way in which the rails were secured to the top of the bowls by the wooden keys. The wooden keys, from exposure to the sun and the rain, and from the vibration of trains, soon worked loose; the result of which was, that the rail rocked and jumped in the chair. The passing trains being thus enabled to spring the rails, gave a series of successive blows to the top of the bowls, which was the chief cause of the sonority and rigidity of the pot sleepers now in use. He thought, that by proper construction this might be overcome, and he had effectually succeeded in doing so by casting the 'pot' in two pieces, with a sufficient length of chair-jaw to firmly grasp the sides of the rail, by keying up through legs cast on to the bowls underneath the bottom of the rail. The 'pot,' by this method of construction, followed the minute deflections of the rail, the rattle of the rail in the chair was prevented, and the wooden key was dispensed with. He did not mean to say, that he could make a road equal to the wooden cross-sleeper; at the same time he thought that the 'pot' bearing surface was credited with defects that did not necessarily belong to it. The 'pot' sleeper was the only iron road he was aware of that was embedded well in the ballast, and which, therefore, had sufficient hold; and he knew of no other form of cast-iron road that was likely to succeed in practice.

Mr. John Bethell had no means of giving any information, respecting the relative durability of materials in tropical climates, as he had no experience on the subject. Mr. Gregory had correctly stated, that the durability of wood depended very much upon whether it was, from its nature or situation, subject to be alter-

nately wet and dry, and further, upon whether it was soft or hard wood. There was no doubt, that a piece of wood which was wet one day and dry the next, and exposed to considerable heat, was liable to decay very rapidly; and, in the use of native, unprepared wood, it would be safer to select that part which was hard, and which, from having all the pores filled up with ligneous matter, did not so freely absorb moisture. A piece of unprepared hard wood was not liable to get wet or dry so frequently, because it did not absorb water so readily as the more porous qualities of wood; but it was the reverse when wood was selected for creosoting, and it was to that particular point he had often urged the attention of Engineers, but he was sorry to say, as far as sleepers were concerned, with little effect. In fact the specifications issued for sleepers for foreign railways had been of such a character, that he had felt it was utterly impossible to comply with them. These specifications described the sleepers to be entirely of heart wood, and then to be creosoted to the extent of 10 lbs. of the oil per cubic foot. If the heart-wood sleepers were employed it was impossible to creosote them to that extent, and he defied any one to get 10 lbs. per cubic foot into heart-wood timber. He had samples in his possession, which tended to show, that the great value in creosoting was to retain the young wood as much as possible. The creosoting process was not, as often described, a chemical process entirely. It was so to a certain extent, because the creosote oil was the strongest coagulator of the albumen in the sap of wood. But that was not his only idea when he introduced the process; his object was also to fill the pores of the wood with a bituminous asphaltic substance, which rendered it waterproof, and by which, in process of time, the wood so treated became very much more solid and harder than heart-wood itself. That result was fully shown by some specimens he had received from Belgium, of half-round sleepers creosoted by him fifteen years ago, which showed that all the young wood had become set, as it were, into a piece of solid alphalte; and Scotch fir and Baltic timber, which had their pores filled with this tar-oil, became entirely waterproof, and so hard that it was with the greatest difficulty they could be sawn. Of Scotch fir sleepers laid on the North Eastern Railway in 1841, 80 per cent. were doing duty at the present time, and such cases of decay as had occurred, were found to have taken place in the heart-wood, where the creosote had not penetrated. The Engineer of the Belgian State railways sent him some specimens not long ago, which illustrated the same fact. He found one specimen which had lost a piece of its heart by decay; but on experimenting upon the transverse strength of that sleeper against a similar sleeper uncreosoted, it was found quite as strong, though it had lost its heart,

because, from the thorough impregnation of the bitumen, the young wood had become so hard that it was more like an iron pipe; and he was satisfied that if it lost all the heart, it would be stronger than a sleeper in its natural state. It was stated in Mr. Mann's Paper, that the half-round creosoted sleepers lasted better than those of the square form; and this result was to be expected, because the half-round sleeper retained all the young wood, and would have more creosote in it; but in the square sleeper it was cut off. He might state that during the last six years, extensive experiments had been carried on by Monsieur Crepin, the Government Engineer, at the harbour of Ostend, for the purpose of testing the effects of different preservative preparations against the attack of sea-worms on wood, and the result of those experiments was, that wood prepared with corrosive sublimate, or copper, suffered as much from the ravages of the worm as unprepared wood; for though the worm did not affect the timber immediately, yet it did so in a short time; but the creosoted wood the worms did not touch, except where an opening had been left to the heart wood, which the creosote had not reached. The result of those experiments led to the conclusion, that piles used in sea-water should not be squared, but should retain as much young wood in them as possible; and the reason was obvious, that the young wood could be filled with the crosote oil; but if that young wood was cut off, and only the heart-wood left, the creosote could not get into it. The Engineer to whom he alluded strongly recommended that all piles used permanently in sea-works should be entirely round.

Mr. SHEILDS had examined some timber bridges in Pernambuco, during a short visit to that country, and in one, which had only been constructed three years, he found the ends of the timber had been placed in contact with the moist clay; at those places, he could readily knock off the crust of the wood, and the interior of the wood was almost filled with white ants. He had no doubt, the decay was augmented by the contact of the wood with the moist clay. In such a case he would have taken care that the ends of the timber were imbedded in masonry; or that the spot where the wood rested was dry, and well drained. At Bahia he had opportunities of making more extensive observations: and timber there appeared to him to be less affected, generally, by the white ant than in Pernambuco. It had been ascertained, that timber was preserved for a considerable time by being embedded to the depth of about 2 feet in the sea-sand, which protected it also from the attack of the Teredo. Timber was stored for the Government works in considerable quantities in that way, and, having in some instances been forgotten, discoveries of seasoned wood were occasionally made on the shore. That fact appeared to show, that timber when

wholly embedded in such situations was suitable for piled foundations, and might also be applied economically by those who had wharves or jetties to build in that country—by forming the underground part of the piles of timber and using iron for the upper portion. He had had opportunities, in the earlier part of his life, of making observations upon Australian timber; and it showed the difference of effects between one climate and another, that in Brazil the more porous and open-grained timbers were most subject to the attacks of the white ant, but that in Australia it was the reverse, for there, it was the hardest description of timber that those insects first attacked. There was one wood in particular in common use to which this remark applied—it was called 'iron bark:' its density was so great that it sunk in water, and its strength was extraordinary, almost approaching to that of inferior iron in tenacity and resistance to strain. It was this wood the white ants particularly attacked. He had tried the effect of coal-tar in destroying white ants. He had taken short baulks of timber where the ants had commenced operations, and tried the system of pouring a very small stream of coal-tar through the heart of the timber which the ants had hollowed out, and afterwards splitting it open to see the result. He found the white ants completely destroyed; they were shrivelled up like shreds of half-burnt paper, by the mere effluvium of the coal-tar; and after that experiment, he never rejected a piece of timber because the white ants had commenced operations upon it as had been previously the custom, whilst he was able to destroy them thoroughly in that cheap way. It was to be remarked, with regard to the timber of Brazil, that it was very brittle: and his experience there led him to the conclusion, that the best course for an Engineer to follow, was as much as possible to have his materials from England; and that iron-work and iron sleepers were peculiarly adapted for a country of that kind. It occurred to him even now, that for tropical climates, wrought-iron transverse sleepers, if it were possible to make them within reasonable cost, would be the best for permanent way; and the next opportunity he had he should endeavour to design something of that sort. With respect to the suspension of the cross-girders of iron bridges from the lower flange of the main girder, instead of from the vertical web, he thought Mr. Mann was right in the remark, that it was better to attach the girder to the vertical web than to suspend it from the flange; but that the correct reason for that opinion had not been stated. The true reason was, that if the cross-girders were attached to the vertical web, they were suspended not from the head but from the shank of the bolts; whereas, if attached below the main girders, they would be suspended, not by the shank but by the head. He thought every practical man knew, that the weakest part of a bolt was

the head or nut, and especially so when it was exposed to any sudden shock, such as the blow of a hammer. He had screwed bolts for experiment very tight, and the fracture occurred generally at the nut, but never in the shank. In attaching cross girders to the vertical web, the bolt, or rivet must be sheared through the shank before a failure could occur; while the heads, which were the weaker part, were only employed in keeping the work together, and were therefore only subject to slight strains. Indeed if both heads were knocked off the rivet, the work might to a certain extent stand good if suspended from the shank, but the work would give way directly under the same circumstances if suspended from the head. For that reason, he thought girders were better suspended from the vertical web (the proper amount of riveting being of course provided as much in one case as the other); as in so doing there would be a clear shear through the shank of the rivet, which presented greater resistance than the head, and was a safer plan for withstanding the jarring of railway trains.

Mr. JOHN CALVERT remarked, that a residence of twenty years in tropical climates had given him some insight into the decay of materials, especially of timber, and he would state a few facts that had come under his observation.

With regard to timber as sleepers, he remembered that eighteen years ago, the Jamaica line was laid with kyanized sleepers, but, in less than twelve months, they were nearly all decayed, after which recourse was had to the native 'cashaw' wood, a species of the acacia something like mahogany in appearance, and as hard. The timber was sawn down the centre and laid with the flat side down, and the sleepers had lasted from that time to the present. A similar wood grew in the Punjab, called Babool, which formed the principal fuel for the steamers on the Indus and Chenaub rivers. It was proposed to use it for sleepers also on the Mooltan and Lahore line, but it was doubtful if a sufficient supply could be obtained. With regard to the depredations of white ants, anything of a bitter taste injected into the fibre prevented their attacks, though it might not have the same effect as coal-tar; but even a small quantity of turpentine had the effect of killing them instantly. The kyanized sleepers he had spoken of were destroyed, not by ants, but by rot. He could confirm the statement with regard to hard woods, that the black ants of the West Indies were more destructive in that quality of wood than in soft, and attacked certain kinds of wood with great voracity. In pulling down the old Cathedral at Jamaica, some of the timbers of the roof, which were of hard wood, were eaten away, and a cart-load of nests, formed by the ants, was removed, after being cut away with great labour by hatchets. There were some descriptions of

wood in the West Indies, such as the Bullet tree and lignum vitæ, which were not affected, either by the teredo navalis, or by the black ant, and when used for piles, were never known to decay. In surveying one of the great lagoons, he remarked an old post of lignum vitæ in water, about 12 feet below the level of the sea. It was in the shape of a cross, and was said to have been placed there by the Spaniards hundreds of years ago. It was not decayed in the water, and very little affected between wind and water. At the Cape of Good Hope, various methods were adopted for preserving the piles used for the jetty. One method was to case them in iron; another was to drive iron nails all over them, in the hope that the oxidation of the heads of the nails would form a coating on the outside, and defend the timber from the worms. In India, the white ants were exceedingly destructive. In piles of sleepers which had been lying ready for use about eight months, at least 10 per cent. were found decayed at the heart. He was inclined to the opinion that frequent vibration, such as was caused by the passage of trains, acted as a protection against white ants; and he knew of an instance in which the timbers of a house were periodically beaten with hammers to keep the ants away. With regard to stone, he had found in the tropics, that the application of linseed oil not only acted as a preservative, but rendered soft stone in the course of a short time so hard, that a chisel would scarcely touch it; and that remark applied to imported Caen stone as well as to the chalk stone found in the West Indies. In Jamaica he found the finest bricks he had ever seen: not only were those bricks well made, but the material itself was good; and there were buildings which had stood from time immemorial without showing any signs of decay. At the Cape of Good Hope, the best mortar was made of shell lime, and, even when mixed with sea-sand, it was exceedingly hard and durable. Both there, and in India, sun-dried bricks were much used for inferior and cheap building. At the former place there were vineyard walls of sun-dried bricks now standing, which were built before the English took possession, the clay being of a tenacious quality.

In the Punjab, however, the clay was very inferior, and soon melted with the rain, so that, when the country was flooded, two or three railway bungalows had been seen to fall in a few days. In spite of this, the Kutcha work (or mud work) was largely adopted. The burnt bricks in the Punjab were not so good, from the extensive exudation of phosphate of soda after the work was built. That defect was, however, remedied to a great extent by covering the bricks with plaster. In the neighbourhood of Agra, telegraph posts of stone, obtained in long lengths, had been adopted to a large extent, in place of timber posts, the rapid decay of which had greatly retarded telegraphic extension in India; but the difficulty

was being met, by making the lower part of the posts of cast iron, into which wooden posts were inserted.

Mr. THOMAS WEBSTER said, that the observations respecting the value of young wood, reminded him of the elaborate experiments which had been made some years ago with chloride of zinc, sulphate of copper, and other chemical preparations; but, in all those cases, the question depended upon the quantity of those salts which could be absorbed in the soft woods. With regard to the chloride of zinc, it had a remarkable property of amalgamating, or uniting, with the albuminous matter of the wood, and thus acted as a preservative. He apprehended that, by these experiments, the value of young wood for these purposes, by reason of the albuminous or other matter contained as a vehicle for uniting with the preserving material, was established beyond all question.

Mr. J. G. COCKBURN CURTIS said, no mention had as yet been made of one of the sources of decay of buildings in tropical climates which he had particularly observed in India. He alluded to the presence and subsequent germination of vegetable matter or seeds in the mortar. When he was employed in the Public Works Department of the Madras Presidency, it was found necessary that periodical inspections should be made to guard against this evil. In some instances, where proper precautions had not been taken, roots had formed very rapidly and of such great size as to bodily dislodge by their pressure large stones from buildings. Mention having been made of the duration of masonry work in India, it might be worthy of attention, whether the practice of the native masons prior to the period of railway engineering had anything to do with it. A proportion of 'Jagherry' or coarse native sugar, varying from about 2 per cent. in ordinary work, to from 5 per cent. to 8 per cent. in arch work, was mixed with the lime. The chemical effects of the 'Jagherry' had been investigated by some Engineers in India, but no very definite conclusions upon the subject had been arrived at.[1]

Mr. J. M. HEPPEL, having been engaged in public works in India, could confirm the statement with regard to "Jagherry" having been used in the mortar, and that the mortar so made, set exceedingly well and was very durable. As the result of his general experience in India, he thought none of the preservative processes for timber which had been mentioned were entirely reliable; and in connection with the Madras Railway he inclined to the opinion, that iron was the only material suitable to the circumstances met with in those climates. With reference to the loss of

[1] *Vide* "Reports, Correspondence, and Original Papers on various professional subjects connected with the Corps of Engineers, Madras Presidency," vol. i., p. 119; vol. ii., p. 192.

metal in rails, he had investigated that question, and found that rails of 72 lbs. per yard had, in one instance, deteriorated to the extent of 3 lbs. per yard by lengthened exposure to the sea air in stacks, though when laid in the sand they lost very little. One great obstacle to the obtaining of reliable results was, that from the nature of the climate, and from other circumstances, offices in India were generally held but for a short time, a lengthened residence in that country being the exception. He thought those Engineers in Great Britain who, from their connection with Indian railways, had accumulated a large amount of information in the reports sent home from various sources, were usually better able to give an opinion on these matters than those who had been resident in India for a comparatively short period of time. Amongst residents, such men as Mr. Berkley, who sacrificed his life to his zeal in conducting a most arduous undertaking, and Mr. Turnbull (to both of whom he had been much indebted for advice and information collected during a great number of years in India), were the men whose opinions on such matters were entitled to the greatest weight, and he preferred to draw upon the experience of such men, rather than to rely entirely upon his own.

November 22, 1864.

JOHN ROBINSON M'CLEAN, President,
in the Chair.

The discussion upon the Papers Nos. 1,122, and 1,125, "On the Decay of Materials in Tropical Climates, and the methods employed for arresting and preventing it," occupied the whole evening, to the exclusion of any other subject.

November 29, 1864.

JOHN ROBINSON M'CLEAN, President,
in the Chair.

No. 1,107.—"Description of the Great Grimsby (Royal) Docks."[1]

By EDWARD HELE CLARK.

GRIMSBY was an important port at an early period of English history. In 1845, it was already supplied with a dock formed from a natural creek. That dock, however, was only 19 acres in area, was shallow, and had a very narrow entrance. Those disadvantages rendered it incapable of receiving the larger class of vessels, for which the increasing commerce of the port required accommodation. Its situation, on the high-water margin of the extremely flat foreshore of the Humber, presented an almost insurmountable obstacle to its improvement. As soon as the railway system was developed, and the advantages afforded by the position of Grimsby, in a geographical and commercial point of view, became clearly understood, a general desire was evinced to make that port the shipping and railway terminus of an extensive and first-class communication. With that object, the Manchester, Sheffield, and Lincolnshire Railway Company became the proprietors of the old haven and dock, and applied for, and received the sanction of Parliament to, a project for new and spacious docks, designed by the late Mr. J. M. Rendel, F.R.S. (Past-President Inst. C.E.), the description of which, and of the works used in their construction, form the subject of this Paper.

The design comprised, besides the principal dock, a large graving-dock, a small dock for the accommodation of fishing craft, two entrance-locks, an entrance tidal basin, and timber ponds of considerable size. (Plate 1, Fig. 2.) It was desirable that the entrance of the new dock should be beyond the limits of low water, afford passage at all times to merchantmen, and be capable, towards high water, of receiving the largest vessels. For this purpose, it was necessary to advance boldly into the river to a distance of $\frac{3}{4}$ths of a mile beyond the old dock, and form an enclosure of 138 acres of land to be reclaimed from the river. This was the first step taken, comprehending the construction of a cofferdam, embankments, and wharves; the boundaries extending nearly $1\frac{1}{2}$ mile in length. In the spring of 1846, the works were commenced, and at the close of the year 1848, the banks and cofferdam were finished, and the

[1] The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

water was excludedfrom the enclosed land. The only portion of the boundary works not intended to be permanent was that part of the cofferdam in front of the entrance to the lock.

In the month of April, 1849, the operations within the enclosure were sufficiently advanced to allow of the first stone being laid by the late Prince Consort, and the works were carried on without failure or delay of any kind, with the exception of some slips of earth-work, which were to be expected from the silty nature of the ground.

The cofferdam was of unusual magnitude,[1] extending 1,500 feet in front of the site of the proposed docks; its plan consisted of two circular arcs with a straight return on the west side, the versed sine of the curved portion being one-fifth of the span. From its situation in the tideway of the river, which runs at the average rate of 5 miles per hour, with a rise of 25 feet, it was much exposed, and as, from the nature of the soil, the usual supports by which such structures are shored were wanting, it was required to be self-supporting and of great strength. The subsoil consists, generally, of a top layer of soft, blue, silty clay, or deposit, averaging 24 feet in thickness; under this is a layer of peat and leaves, averaging 2 feet 6 inches in thickness; then a stratum of sand and gravel; below which is stiff brown clay, averaging 30 feet in thickness; underneath the clay is a layer of green sand, mixed with water, averaging 2 feet thick; and below this is the chalk rock, which is generally reached, in the neighbourhood of Great Grimsby, at depths varying from 80 feet to 100 feet below the level of Trinity high-water mark.

The cofferdam was constructed of Memel fir, in three parallel rows of whole timber piles. The front row was battered half an inch to the foot, and was 7 feet apart from the middle row. The middle and back rows were upright, and were 6 feet apart. The piles in the outer row averaged 60 feet in length, by from 14 inches to 16 inches square; those in the middle row, 47 feet in length, by 14 inches to 16 inches square; and those of the back row 37 feet in length, by 14 inches to 16 inches square. All the piles were hooped and furnished with iron shoes having cast-iron points, weighing 28 lbs. each, and were driven in bays 10 feet apart, each bay being tightly keyed with a wedge key pile.

The puddling, between the rows of piles, was of the best selected clay, mixed, for the first 5 feet in height, with gravel, or small quantities of broken chalk stone; and it was further solidified by being tipped direct from side-tip wagons running on a railway over the dam.

The front and the back row of piles were secured by whole timber walings, five tiers on each side, and the joints of the front

[1] A description of this cofferdam, by Mr. C. Neate, M. Inst. C. E., will be found in Minutes of Proceedings Inst. C. E., vol. ix., p. 1.

row were caulked and pitched, to high-water mark. In the middle row, wrought-iron plates 6 inches deep by 1 inch thick, were substituted for the timber wales. The plates were keyed in lengths of 12 feet, and formed a continuous tie the whole length of the dam. The tie-bolts connecting the rows of piles are $2\frac{1}{2}$ inches in diameter at the bottom tier of walings, and diminish to $1\frac{3}{4}$ inch at the top tier. To prevent a run of water direct through the cofferdam, these were arranged so as not to form a continuous joint, but alternately, one bolt connecting the outer and middle rows, the next connecting the middle and inner rows; and to prevent the water finding its way along them and causing a leak, there was fixed in the middle of each, a cast-iron plate or shield. The counterforts, which supply the place of the usual shorings, were composed of whole timber sheeting piles, and extended 18 feet from the inner row of piles, thus giving to the cofferdam a base of 32 feet: they were connected with the main structure by tiers of whole timber walings, corresponding with those on the inner row of piles, being firmly bolted and secured, by wrought-iron knees and plates, and shored by bridge struts, fitting into cast-iron strut boxes. The boxes were dovetailed, so that the bridge struts might also become ties if necessary. For the purpose of ascertaining the amount of deflection in the cofferdam, gauge-rods were fixed to piles, driven at intervals, along the inside, but perfectly independent of the dam. At high-water spring tides, the greatest deflection was found to be about 3 inches. Two cast-iron circular sluices, 2 feet 6 inches in diameter, fitted with brass-faced doors, and suitable lifting gear, were fixed in the dam temporarily, to carry off the land drainage. A pair of 20 feet flood-gates was also constructed at the east end, to enable the tidal water to be let in or out of the enclosure, as required, until the final closing out of the tide. These flood-gates have since been included in a lock for the fish craft dock. The total quantity of Memel fir used in the construction of the cofferdam amounted to 410,572 cubic feet. The whole of the piles were driven by ordinary pile-engines, worked from two stationary pumping-engines, of 30 H.P., by chains connected with drums fixed on the engine-shafts, the chains being carried over sheaves to the different pile-engines.

The wharf extends from the old dock entrance to the west end of the cofferdam, (Plate 1, Figs. 3 and 4,) a length of 2,431 feet, and from the east end of the cofferdam eastward for a length of 1,208 feet, where it is joined by the embankment. It is constructed of a single row of Memel fir sheet-piles which average from 35 feet to 40 feet in length, and are driven between whole timber walings, strengthened by fender and land tie-piles at intervals of 14 feet. The piling is backed with a dry rubble wall of chalkstone, in the centre of which is a puddle-wall, composed of selected clay, well

punned and rammed. Before commencing the construction of certain portions of the wharf, particularly that part eastward of the cofferdam, it was found necessary to load the ground with layers of chalkstone, for in that place the natural bed of stiff, brown clay appeared to have been broken through and replaced, as far down as the chalk rock, by soft silty clay, mixed with sand. This fault in the soil began at the south-west corner of the enclosure, and extended eastward, intersecting the wharf at about a distance of 300 yards east of the cofferdam. The chalkstone, however, by gradually displacing the silt, at last reached a firm foundation, forming a large bank with natural slopes of about 7 to 1. Great difficulty was experienced in securing the puddle-lining of the bank, owing to the occurrence of numerous slips; and the sheet-piling and land tie-piles at these places are much distorted, and out of the level, from the same cause; but since the chalk has assumed its bed, the latter have not moved, and now form a breakwater to protect the chalk slope.

The eastern embankment (Plate 1, Fig. 5), completing the enclosure, extends 1,800 feet in length from the east end of the wharf, to high-water mark on the foreshore, and is, in the centre, composed of a puddle-wall of the stiff clay thrown up from the foreshore, faced on the sides with chalkstone, having a slope seaward of 1 foot vertical to 3 feet horizontal, and inland of 1 foot vertical to $1\frac{1}{2}$ foot horizontal.

As soon as the wharves, cofferdam, and embankment were completed, the excavation for the foundations of the locks and walls was commenced, and the whole area of the enclosure was drained by pumps worked by two engines of 35 H. P. Several fresh-water springs occurred in the course of excavating, which considerably endangered the safety of the foundations, by bringing to the surface large quantities of black sand. These were, however, in a great measure reduced, by bringing the water up in wrought-iron pipes, and also by weighting the surface round the springs with chalkstone.

The entrance to the main dock consists of two locks, (Plate 2, Figs. 1, 2, and 3, and Plate 2A, Figs. 1, 2, and 3,) separated by a pier of masonry 70 feet in width. The large lock is 300 feet in length between the pen gates, and 70 feet in width, and the small lock is 200 feet in length by 45 feet in width. The cills of the 70-feet lock are laid 6 feet below low-water mark, and the cills of the smaller lock are laid 9 inches lower than the large lock, or 6 feet 9 inches below low-water mark at ordinary spring tides. Each lock is provided with two pairs of pen-gates and a pair of flood-gates. For the foundations of the locks, centre pier, and wing walls, the ground was excavated over the whole area to a depth of 8 feet below the cill of the large lock. Rows of Memel fir sheet-piling, 12 inches square and 35 feet long, were then

driven, between two whole timber wales, in bays 10 feet apart across the width of the locks and centre pier, in front of the aprons of the locks, and under the gate-cills. Bearing-piles of English and Memel fir, averaging 35 feet long, by 13 inches square, were then driven in rows 5 feet apart from centre to centre, and in some places, 4 feet apart from centre to centre, over the whole area. The machines used for this purpose were two of Nasmyth's steam pile-driving engines, in addition to the ordinary pile-engines worked by manual labour, having rams weighing 1 ton each. A pile was considered as sufficiently well driven when it refused to move more than a $\frac{1}{4}$ of an inch with a blow of the ram from a fall of 12 feet. The heads of the piles were then cut to a level, and the ground removed to a depth of 2 feet below them; the space thus made was filled up with concrete, composed of four-ninths of small broken chalkstone, two-ninths of Spurn gravel and two-ninths of clean sand and refuse from the Company's stone fields, well mixed and incorporated with one-ninth of ground blue lias lime, with just sufficient water to make the materials bind together. Whole timber Memel fir baulks were then laid transversely across the lock and centre pier, in parallel rows, on the bearing-piles, in as long lengths as possible, and were jointed together with long scarfs, and secured with iron plates and keys, so as to form a continuous tie across the whole width of the locks and centre pier. The transverse beams were fastened to the piles by long wrought-iron jagged spikes $\frac{3}{4}$-inch square. The intervening spaces were then filled with concrete to the level of the upper surface, and long whole timber Memel fir baulks, 13 inches square, were spiked to the transverse beams at right angles to them, the joints being scarfed and keyed, in the same manner as the transverse beams. Concrete was then filled in to the level of the upper surface of the longitudinal timbers; and on these a planking, of beech and Memel fir, was spiked, to form a bed for the masonry of the superstructure. Exclusive of sheeting piles, 6,180 piles of English timber, chiefly of elm and Scotch fir, and containing upwards of 254,000 cubic feet, were driven in the foundations of the locks, centre pier, and wing-walls. The inverts and platforms for the gates are wholly of stone. The pointing cills are straight, and are notched out of the solid, 1 foot 6 inches, at their junction with the platform courses, which are 3 feet thick. The joints of the masonry radiate horizontally and vertically, corresponding with the radius of the inverts. The masonry of the gate-tables is 4 feet 6 inches thick, that of the hollow quoins for the lock-gates is laid in courses, each stone averaging 5 feet 6 inches, by 4 feet 6 inches, by 2 feet thick, placed alternately in a longitudinal and transverse direction, and counterforts of solid rubble masonry are brought up behind each of these quoins. The inverts of the chambers of the locks are of stone, averaging 3 feet

in thickness, laid on a bed of concrete formed to the radius of the invert. Communicating with the dock are three main culverts; one situated in the centre pier, and one in the side wall of each lock, serving to fill and empty the locks and to scour the entrance channel. To contribute to this purpose the culverts in the side walls are carried down the wing walls, with branches at intervals. There are also outlets from the main culverts into each gate recess, for the purpose of cleaning the gate-tables. The branch sluices, for filling the locks, open into the head of the lock chambers near the inner pen-gate, and are provided with sluice-doors, wedge-shaped, and of oak: each door works in stone grooves, and is lifted by hydraulic power by means of a separate cylinder, by direct action. The copings of the front of the centre pier, and of the wing-walls facing the sea are set with the upper surface at a level of 35 feet above the cill of the 70-feet lock; but inside the flood-gates, the coping slopes down to a level of 35 feet above the cill, which level is maintained on both sides of the locks and centre pier. The coping is 6 feet wide, by 2 feet thick, and is secured at each joint by a hard stone dowel, 8 inches square. The surface of the centre pier and side walls of the locks is paved with Yorkshire flag-stones, 6 inches thick. The masonry of the pointing-cills, gate-tables, inverts, aprons, platforms, square quoins, and culverts is of Bramley Fall stone; the hollow quoins are of stone from the Calverly Wood quarries; the backing to the walls is built of the best-selected chalkstone, from the quarries of Hessle, in Yorkshire, and Melton Ross, in Lincolnshire, hammer-dressed, laid in regular courses, and bonded with the ashlars.

The dock walls were formed of long piers, with brick arching between (Plate 2A, Figs. 4, 5, and 6), and, in this respect, differed from the usual mode of construction. It was evident, that upon a site such as has been described, and with a backing of a soft, silty character, the ordinary retaining walls would have been insufficient, particularly as good foundations were required for the granaries, transit sheds, and heavy machinery which were to be erected upon the adjoining quays. The piers, which are generally 6 feet thick, except at the north end of the dock walls, where the thickness is increased to 15 feet to provide foundations for cranes, vary in length from 80 feet to 40 feet, and were built of chalk rubble masonry, arched over with brick; the front part, next the dock, being protected by an ashlar facing, averaging 18 inches thick, to form the quay. The arches are five half bricks thick, the spandrils being of concrete. The coping of the walls is 4 feet wide by 2 feet thick, and is dowelled in the same manner as that of the locks. The backing, which, from the back of the arch to the bottom of the dock has a slope of $2\frac{1}{2}$ to 1, is composed of puddled clay, faced with undressed chalkstone laid roughly.

The quay is provided with cast-iron mooring-piles, placed at intervals of 100 feet apart, and the level of its surface is 32 feet above the cill of the 70-feet lock. The foundations of the piers are of piles and concrete similar to those of the locks, the piles averaging 35 feet in length; but in some places it was necessary to drive them as long as 50 feet and 60 feet. The stone used for the facing of the arches and piers, and for the coping of the quays, was from the Bramley Fall quarries.

The limestone used in the preparation of the mortar and concrete lime was entirely of blue lias, from Lyme Regis, and cost, delivered at Grimsby, 10*s.* 6*d.* per ton. It was broken into small pieces before being put into the kilns, and after burning forty hours, was stored in a covered shed. In making the mortar, which was of two classes, the lime was first slacked, and then, with the other materials, was well ground and mixed in the pans for fifteen minutes, just sufficient water being added to render the mixture fit for use.

The first class, which was chiefly for pointing and face work, was composed of ten parts of slacked lime, eight parts of screened sand, one part of forge ashes, and one part of pozzolano. Its cost was about 16*s.* per yard. The second class, used principally for the backing of walls and rubble masonry, and for brickwork, was composed of sixteen parts of slacked lime, twenty parts of screened sand, three parts of forge ashes, and one part of pozzolano, at a cost of 12*s.* per yard.

Two lime-kilns and six mortar-mills were erected adjoining the works. The mills were of the ordinary description, two stones moving in a revolving pan, and were worked by a beam engine of 25 H.P., which, with the boilers and the rest of the machinery, were supplied by Messrs. G. Forrester and Co. of Liverpool, and cost £3,381. The total cost, including lime-kilns, all the machinery, and buildings, was £5,000.

To each lock there are two pairs of pen-gates and one pair of flood-gates, alike in principle and construction, though of different dimensions. (Plate 3, Figs. 1, 2, 3, and 4.) Both are of timber, and, as the bars are trussed by wrought-iron straining-rods, they are, in fact, girders. The timber is chiefly oak from the Black Forest; teak and mahogany being also used, on account of the difficulty of procuring sound oak of the required scantlings. Each leaf of the flood-gates of the 70-feet lock, is, from the bottom of the lowest bar to the upper surface of the top bar, 32 feet in height, and the width from the back of the heel-post to the face of the mitre-post, is 42 feet, each leaf, when complete, weighing about 75 tons. At the time of their erection these gates were considered to be the largest yet constructed. The heel-post of the gate is struck to a radius of 12 inches. The morticed faces of the heel-posts

and mitre-posts are bevilled $2\frac{1}{4}$ inches in the width of the post, to take a portion of the strain off the tenons of the bars. The meeting face of the mitre-posts is 10 inches wide. The bottom part of the gate, from the under side of the lowest bar to the height of 10 feet 6 inches, is composed entirely of oak beams framed solid; next are three tiers of triple and double bars, and then a single bar at the top of the gate, straight on the inside, but with a small camber of about 3 inches on the outside. The intervals between them are planked with 3-inch thick oak planking, let into rebates in the bars and posts, and secured thereto by galvanized iron screws. Distance pieces are inserted at the heel and mitre-posts. Two vertical timbers, each 12 inches square, are bolted to the bars of the gate, about 12 feet apart, in the centre of the leaf; on these are fixed cast-iron saddles to receive the straining rods, of which there are six in each leaf. Each truss-rod is composed of three separate pieces; that for the centre length is made of flat iron, $1\frac{3}{4}$ inch by $1\frac{1}{2}$ inch, with cheeks at each end. The two side lengths are of round iron, 2 inches in diameter, fitted with an eye at one end, and a strong thread and hexagonal nut at the other. These two lengths are shackled to the centre piece, their other extremities passing through the heel-posts and mitre-posts respectively, the whole being screwed up, and the nuts let into the heel-posts and mitre-posts. The T and angle-plates connecting the heel-posts and mitre-posts to the bars of the gates are of wrought iron, 5 inches wide by 1 inch thick, and are let flush into the timber. The plates are swelled and notched at the bolt-holes, for the purpose of taking better hold of the timber. The whole of the iron work was obtained from Lowmoor.

When the large lock-gates were being erected, it was found that the ordinary rollers fixed on the outside of the gate, being out of the vertical plane, caused the leaf to twist considerably. To remedy this defect, it was resolved by Mr. Rendel, to fix two rollers, one on each side of the gates, both travelling in the same path (Plate 3, Figs. 5, 6, and 7); the inner roller was necessarily smaller than the outer one, the depth of the meeting-cill of the gate-platforms being only 18 inches; and for this reason it was requisite that there should be a box, into which the inside roller might fall when the gate was closed. This box was of cast-iron, was let into the stone cill, and was made with a false back or door, secured by a cast-iron bar let into a groove at the back. This provision was made to prevent the injury which must have accrued from the entrance of hard substances into the valve-box, in which case, when the gate was closed against the cill, the inside roller would have forced the obstruction against the door, broken an ordinary bar, and caused a leak; but with the actual arrangement, the bar has only required to be replaced once a year, during

the twelve years the rollers have been in use for the three pairs of gates. The roller-paths are of cast iron, of a tubular section, of great strength, let into the masonry of the gate-platforms; and a planed cast-iron plate is let into the masonry, under the joints of the roller-path, to insure perfect evenness throughout.

The gudgeons, on which the heel-posts of the gates revolve, are of solid cast iron 9 inches in diameter. The cup is also of cast iron, fitted into the horn of the heel-post. In the top of the cup there is a piece of brass of a convex shape.

The anchor-plates are of cast iron, and quadrant-shaped, the length of the back arc being $8\frac{1}{2}$ feet. (Plate 3, Figs. 8 and 9.) These are cast in one piece, are firmly let into the masonry, are secured by lewis bolts and lugs, and are run in with lead. The anchor-straps are of the best wrought iron, 7 inches deep by $1\frac{1}{4}$ inch thick, and are keyed behind the lugs in the anchor-plates, in the usual manner. Cast-iron heel-caps are fitted to the heel-posts, the part against which the straps work being faced with brass.

The pointing-cills, which are straight, and correspond with the bottom bars of the gates, are protected by cast-iron face-plates 9 inches in depth, secured to the masonry by lewis bolts. The plates are jointed and planed, and form a perfectly water-tight joint. Bridges, 6 feet wide, supported on strong cast-iron pillar-brackets, are fixed on the pen-gates of both locks, and are provided with wrought-iron hand-rails, which are capable of being let down, so that ropes may be passed over when vessels enter the locks. The cost of a pair of gates for the 70-feet lock was £2,300, exclusive of the machinery for working them.

The whole of the machinery, including rollers and paths, was supplied by Sir W. Armstrong, and was the first apparatus of the kind designed by him for the purpose of working dock-gates. The crabs for opening and shutting the gates are worked by an endless chain, set in motion by the piston-rods passing through both ends of three large cylinders, one of which is placed on the centre pier, and one on each side of the locks, and are arranged so as to be worked by hand-power, in case of any derangement of the hydraulic machinery. The chains are linked, and work into toothed wheels, in connection with the drums on which the gate-chains are fixed. Each drum is provided with a break and disconnecting gear, so that they can be set free from the toothed wheel when necessary. The cost of the apparatus for working the gates of both locks, including foundations, and cast-iron pits for the chains, was £4,000. The motive power is obtained from the hydraulic pressure gained from a tank of water placed in a tower 200 feet in height. The water is forced into the tank by two 10-inch force-pumps, worked by a duplicate horizontal engine of 25 H. P. Two men only are required to work the gates of both locks, which are

capable of being opened in two minutes and a half, and the machinery, which has now been in constant use for ten years, has answered admirably, and has required very few repairs.

The timber piers bounding the tidal basin (Plate 3, Figs. 14 and 15) commence at the extremities of the stone wing-walls, extend into the river, and terminate with a circular pier-head at each side, forming together an entrance 260 feet wide. These pier-heads are of great strength, being tied and shored by whole timber-braces and wales. The construction is of open timber, in bays of piles in clusters, each bay being 25 feet apart. The front piles average 50 feet in length and 14 inches square, and are driven with a batter of a quarter of an inch to the foot. The interior or abutting piles average 36 feet long and 14 inches square. Each pile is shod with a wrought-iron shoe weighing 28 lbs. The piles are supported and shored by walings and diagonal braces, secured by wrought-iron bolts $1\frac{1}{4}$ inch square. The outside of the piers facing the sea is protected by half timber fender-pieces, spiked to the walings, which answer the double purpose of keeping the heavy seas from injuring the lock gates, and of preventing the rush of the tides through the basin.

The planking is laid with spaces of three-quarters of an inch, to allow for ventilation, and wrought-iron mooring-rings are fixed at intervals of every 100 feet along the inside of the piers. Throughout the structure, the timber, after being perfectly dried, was creosoted with great care by Mr. Bethell's process, in works erected on the dock premises: the creosote being injected at the rate of 45 gallons per load. Each piece of timber was accurately weighed before being put into the tanks, and when taken from them, and was rejected to be recreosoted, if not found to contain the standard quantity.

The channel, from the mouth of the basin to the entrance locks, averages 260 feet in width, and is kept to the level of the lock-cills by frequent scouring and occasional dredging. Immediately outside the tidal-piers it deepens to 3 feet below the level of the large lock-cills, and the scour of the tides past the pier-heads has gradually deepened it, since the construction of the dock works, from 3 feet to 4 feet. In addition to the means provided for sluicing the silty deposit from the channel of the tidal basin, the back water from the country, which originally flowed into the old dock channel, is now brought from the drain near the Cleethorpe's road, in a brick culvert 6 feet in diameter, to the end of the east dock wall, from whence it is carried through the piers of the dock wall, in a cast-iron pipe to the north end of the dock. From this point it is carried in a brick tunnel 6 feet in diameter, under the entrance to the graving-dock, into the main culvert of the 45-feet lock, and from thence into the tidal basin.

The graving-dock (Plate 3, Figs. 10, 11, 12, and 13,) which, through want of funds, was not constructed till after the opening of the new dock, is situated at the north-east end of it, adjoining the 45-feet lock, provision having been made for that purpose, by building an entrance in the retaining-wall, 70 feet in width, which was blocked up by a chalk rubble masonry dam, during the construction of the main works. This dock is, at its entrance, 70 feet in width, and at the level of the coping its width is 96 feet, tapering to 84 feet at the end. Its length, for keel on the blocks, is 350 feet: the width of the floor is 52 feet. Its cill is laid at the level of 6 feet above the cill of the large lock, giving an average depth of water of 19 feet 6 inches. The foundations for the dock were formed by making a box of solid concrete: this was effected by driving a row of Memel fir sheeting-piles, 30 feet long and 9 inches thick, tongued and grooved, round the outside of the space intended for the walls. After the piles were driven, the soil was removed to a depth of 6 feet below the pile-heads, over the whole area of the dock, and the space was filled up with concrete, made with ground blue lias lime, and levelled off for the foundations of the walls and gate-tables. Some trouble was experienced in preventing the line of the sheet piling being broken by the pressure of the silty clay on the back of the piles, when excavating for the concrete. This was, however, overcome, by shoring them from the rows of piles which had been previously driven under the centre line of the graving-dock, to support the weight of the ships when blocked.

The inverts and gate-tables are of Bramley Fall stone, averaging 3 feet 6 inches thick. Their joints are radiated vertically and horizontally, as described for the 70-feet locks.

The floor of this dock differs in form from the ordinary floor of graving-docks, in being convexed, instead of inverted or flat. By this method, freer ventilation round the sides of the vessels is obtained, as well as ample room for the shipwrights and artisans to get at their work. The floor is drained by gutters round the side of the walls, delivering into a well. The floor is constructed of hard stone sleeper-blocks, keyed in the centre by key-stones, 6 feet wide by 2 feet thick, which also form a bed for the blocks which support the vessels. The stones, 4 feet by 2 feet, which form the gutter round the floor, also form the springing stones of the arch, and were, together with the key-stones, obtained from the Bramley Fall quarries. The steps are each 3 feet in height, with a 3-feet tread, formed of brickwork, and coped with Bramley Fall stone 18 inches thick, and backed with chalkstone rubble masonry set in second-class mortar. The coping-stones average 6 feet wide by 2 feet thick, and the joints are dowelled with stone dowels 8 inches square. There are four pairs of steps, and four slides for timber in the sides

of the dock, and two slides and three flights of stairs at the end.

The supply of water is by a culvert, 6 feet by 4 feet, direct from the Royal Dock, and the drainage, to the depth of low water, is effected by a branch from the same culvert into the main culvert on the east side of the 45-feet lock. The culvert is provided with two sluice doors, worked by hydraulic machinery. One of the doors shuts off the water from the Royal Dock; the other is fixed in the branch to the 45-feet lock culvert, and is used when the dock is required to be drained at low water. As the graving-dock, however, can only be partially drained into the tide-way, the ordinary low water of spring-tides never being below the cill of the dock, and the floor of the dock being 3 feet below that level, it is necessary to pump from 3 feet to 4 feet depth of water. This is effected by a centrifugal pump, fixed in the well adjoining the dock. It delivers the water at the rate of 3,600 gallons per minute, and is worked by an engine of 25 H.P., which also operates upon two suction-pumps of 10 inches in diameter, that are used to discharge the accumulation of water that results from the leakage when vessels remain long in the dock. When these pumps are being worked, the centrifugal pumps are capable of being put out of gear with the engine, and *vice versâ*. The engine is supplied by two egg-ended boilers, each 30 feet long and 6 feet in diameter, and it makes 40 strokes per minute, when working the centrifugal pumps. The latter are found peculiarly suitable to the drainage of graving-docks, not being liable to be choked, as are the valve pumps, by the great quantities of chips and rubbish which find their way into the well.

The gates of this lock are, in material and construction, exactly similar to those of the 70-feet lock, and have the same description of roller and anchor plate, but are worked by powerful double-purchase crabs only; graving-dock gates being so seldom used in comparison with lock-gates, that it was justly considered unnecessary to incur the expense of hydraulic machinery. The total cost of the graving-dock, including engine-house and well (but not including the engine and pumps), was £32,000. This dock was designed by the late Mr. Adam Smith (M. Inst. C.E.), and its construction was superintended by the Author; the contractor for the work was Mr. James Taylor, of Manchester.

From the rapidly increasing coal trade at this port, since the docks were opened, and the railway communication established with the Yorkshire coal-fields, it was found necessary to increase the accommodation for shipping coal. This has been accomplished by the formation of two lines of railway, which run into the dock, through the timber ponds, with coal spouts at their extremities. One line of rails is carried down the centre of the dock, and the

other line branches to the west. The rails are laid on a timber staging, constructed of long piles driven in bays 24 feet apart, the longitudinal timbers being supported by bridge struts. The coal spouts, or wrought-iron shoots, are fitted with hinged joints, and are capable of being raised, or lowered, by winches to the height of the deck of the vessel loading. The coal wagons are brought to the end of the piers, which are, at these points, at an elevation of 12 feet above the dock coping level, are placed over the spouts, and the doors in the bottom of the wagons being then opened, the coals are directed by the spouts into the hold of the ship. Breakage of the coal is, in a great measure, prevented by a door being fixed inside the spouts, hinged to one of its sides, and connected by a chain with a winch above: by this means, the pace at which the coals enter the vessel is kept perfectly under control. The wagons, when emptied, descend by their own gravity down the empty line.

Owing to the crossing at the Cleethorpe's road entrance to the docks, which has to be traversed at a level, the gradients of the railways are rather steep, averaging 1 in 70, but an ordinary locomotive engine can easily take up twelve or thirteen wagons of loaded coal at a time. Each coal spout can load about 400 tons of coal per day.

The hydraulic tower, which is a fine specimen of plain brickwork, stands at the outer or sea end of the centre pier, and was designed to serve as an accumulator of water pressure for working the machinery of the lock-gates and cranes, and also to supply fresh water to the shipping. A wrought-iron tank, capable of holding 33,000 gallons of water, is fixed at the height of 200 feet on a projecting corbelling. (Plate 3, Figs. 18 and 19.) The total height of the tower to the top of the lantern is 300 feet. It is rectangular in form, and measures at the base 28 feet square, tapering to 26 feet to the underside of the first projections. The walls are 4 feet thick at the base, and 3 feet thick at the string course under the corbells. The bricks, which were made on the Company's premises from clay obtained from excavations in the marsh adjoining the works, are set in the best blue lias mortar, and hoop iron bond is used in the walls to a considerable extent. The water is conveyed in a cast-iron pipe, 13 inches in diameter, down the east side of the dock, across the graving-dock entrance, and across the 45-feet lock to the tower, where it is forced into the tank by two force-pumps, each 10 inches in diameter, worked by a duplicate, horizontal engine of 25 H.P., situated at the entrance to the dock premises. This main, a branch of which extends to the west quay wall, supplies the pressure to the dock-gate machinery and sluice doors, also to the fifteen hydraulic cranes on the dock quays, and in the warehouses, besides supplying the wants of the shipping in

the dock, and the dwelling-houses on the dock premises. The water for the supply of the tower is derived from a well, 15 feet in diameter and 47 feet deep, with a boring of 5 inches in diameter to the chalk rock in the centre. The well is also fed by seven borings of 5 inches in diameter, at intervals in a length of 300 feet, which discharge into the well by a brick culvert 3 feet in diameter.

In addition to the engine and pumps already described, there is a large Cornish engine capable of lifting 8,000 gallons of water per minute. It was intended for the supply of the Royal Dock, and was provided with a separate well 20 feet in diameter and 60 feet deep, which was fed by a large boring 6 feet in diameter to the chalk rock; but the supply from the chalk having failed, the docks are no longer supplied with fresh water, but with tidal water. The use of these pumps is therefore discontinued. All the engines, pumps, and pipes, and the whole of the machinery (Plate 2, Fig. 4) were, with the exception of the Cornish engine and pumps, which were made by Mr. Mitchell, of the Perran Foundry, Cornwall, furnished by Sir W. Armstrong.

Transit sheds, bonding warehouses (Plate 3, Fig. 20), passenger station, and other accommodation for traffic, are constructed on the east side of the dock; and tramways and turn-tables, in connection with the main line of railway, are laid down for the purpose of conveying goods to the cranes in the warehouses and transepts.

The fishing-craft dock (Plate 3, Figs. 16 and 17) is about 6 acres in extent, and has been constructed, since the opening of the new dock, to provide for the greatly-increasing trade springing up at Grimsby, as many as three hundred smacks of about 40 tons each sailing from, or calling at this port. This dock is situated at the east side of the entrances to the new dock, the flood-gates of the cofferdam forming those of the fishing-dock lock, which is 80 feet long by 20 feet in width, having an average depth of water, at high-water ordinary spring-tides, of 15 feet 6 inches, the cills being laid 10 feet above the level of those of the large lock. The lock has also two pairs of pen-gates, with sluices in each pair of gates, for the purpose of filling and emptying the locks, and scouring the outfall. The sides of the dock are formed with clay slopes, with an average batter of 3 feet horizontal to 1 foot vertical, and are covered with chalkstone, roughly pitched, except on the south side of the dock. On this side, a timber wharf has been erected 400 feet long, by 35 feet wide, 25 feet of the width being roofed over. Under this roof the fish is landed, and packed for the markets. A branch line of rails from the main line runs along the back of this pier at a level of 4 feet below the surface of the planking pier, so that the fish baskets, &c., may be wheeled directly into the wagons.

The pier is constructed on long Memel fir piles, in three parallel

rows, the front row averaging 50 feet in length, the two inner rows 30 feet, with cross heads and planking. The total cost of this dock, including the timber wharf, was about £12,000.

The contractors for the whole works, were, for the cofferdams, Messrs. Lynn, of Liverpool, and for the completion of the dock works, Messrs. Hutching, Brown, and Wright, who have ably carried out the construction under the superintendence of the late Mr. Adam Smith (M. Inst. C.E.).

To add to the improvements already effected, it is in contemplation to connect, by a cut, the old and the new docks, the former being still exceedingly useful for some classes of trade, particularly that of timber, for which it is admirably adapted. By this operation, it is hoped that the convenience and accommodation of the port of Grimsby will be complete.

In conclusion, the Author would offer some remarks upon a circumstance of great importance to the future welfare of Grimsby. For several years there has been a gradual wasting away of the promontory on the Yorkshire coast, opposite to Grimsby, known as the Spurn Point. He believes, that upon the maintenance of this neck of land depends, as it were, the existence of the port. About eight or nine years since, when the inroads of the North Sea threatened to make a breach between Spurn Point and the main land, the late Mr. Rendel drew the attention of the Government to the subject, as he feared that if a permanent breach were effected, the channel of the Humber would be diverted from the Lincolnshire coast, and form for itself a new outlet into the North Sea. He also foresaw the probable silting up of the channel immediately in front of the docks. In consequence of his representations, the breach was made up by tipping large quantities of chalkstone upon the foreshore; but since that period no further works have been executed for the purpose of protecting this Point. The rubble then put down is being gradually broken up and washed away; and, unless the Government take immediate measures for the preservation of the bank, it is more than probable that Mr. Rendel's fears may be realized. In the course of such protective works, it might also be advisable to reclaim the tracts of land at present covered at high water by the sea, and lying on the Yorkshire coast, between the lately reclaimed land called Sunk Island, and the Spurn Point. (Plate 1, Fig. 1.)

The Paper is illustrated by seventeen drawings, from which Plates 1 to 3 have been compiled.

[APPENDIX.

APPENDIX.

TABLE I.—STATEMENT, showing the AREAS of the different DOCKS and BASINS, and DEPTHS of WATER in the Docks and Locks belonging to the MANCHESTER, SHEFFIELD, and LINCOLNSHIRE RAILWAY, at GRIMSBY.

1.	Area of the new dock, now called "Royal"	20 acres.
2.	Timber pond in ditto	5 „
3.	Tidal basin	13 „
4.	Fish-craft dock	6 „
5.	Area of quays of Royal Dock	22,000 yards.
6.	Total area of land reclaimed	138 acres.
		Ft. In.
7.	Depth of water in Royal Dock	25 6
8.	Depth of water on cill of 70-feet lock at high-water ordinary spring-tides	25 6
9.	Depth of water in cill of 70-feet lock at low-water ordinary spring-tides	6 0
10.	Depth of water on cill of 70-feet lock at high-water ordinary neap-tides	22 0
11.	Depth of water on cill of 70-feet lock at low-water ordinary neap-tides	10 0

The cills of the 45 feet, or smaller lock, being laid 9 inches lower than the 70-feet lock cills, there is consequently 9 inches more depth of water than the depths stated for the 70-feet lock.

The level of the Fish-craft Dock lock cill is laid 10 feet above the cill of the 70-feet lock.

TABLE 2.—RISE and FALL of TIDES in the HUMBER.

High-water ordinary spring-tides rise 19 feet 6 inches above low-water ordinary spring-tides.

High-water equinoctial spring-tides rise about 23 feet above low-water equinoctial spring-tides.

High-water ordinary neap-tides rise 12 feet above ordinary low-water neap-tides.

TABLE 3.—STATEMENT showing the increase of TRAFFIC to GRIMSBY since the opening of the NEW DOCKS.

In 1853, the number of vessels to and from foreign ports was 530, with a tonnage of 134,334 tons.

In 1863, the number of vessels to and from foreign ports was 1,367, and tonnage 317,593 tons.

Increase in ten years, 837 vessels and 183,259 tons.

The fish forwarded by rail from Grimsby in 1863, was 10,360 tons; in 1852 the weight was 500 tons.

The weight of timber imported into Grimsby in 1863, was 121,604 tons.

Value of exports up to the present time, 1864, £4,852,448. Corresponding period last year £3,456,855; or increase £1,395,593.

The quantity of coals exported from Grimsby in 1863 was 170,000 tons. In 1853 the export was nil.

Mr. E. H. Clark said, that the cost of the dock walls per lineal yard, including excavating, piling, and masonry was £110; the cost of a pair of gates, at 25*s.* per square foot, exclusive of the machinery, was £2,300; and the reclaimed land, on the foreshore of the Humber, was purchased from the Government, by the Manchester and Sheffield Railway Company, for £30,000. The timber used in the construction of the cofferdam and exterior works of the enclosure amounted to 709,000 cubic feet, of which 410,572 cubic feet were required for the cofferdam alone. The cost of the cofferdam was £70,000, being at the rate of £46. 10*s.* per running foot. The total expenditure on the Great Grimsby Docks was about £1,050,000. Of this sum £112,207 was for the purchase of the old dock and outfall, while the remaining amount, £937,793, was expended on the construction of the docks and the reclamation and purchase of land, no interest on capital being included in these amounts. He wished to bear testimony to the great value of creosoting for the preservation of timber. He had lately examined the tidal pier, and had observed, that some of the uncreosoted piles, which were originally 14 inches square, were now wasted considerably, had lost half their thickness, and were merely hanging by the bolts; whereas the creosoted timbers were as sound as when first driven.

Mr. Coode remarked, with reference to the threatened breach through the Spurn Point, that he considered the preservation of the promontory was of paramount importance to the harbour and port of Grimsby. The Board of Trade had, some time since, referred the matter to him, and he had recommended the construction of timber groynes upon the beach facing the North Sea. Some of these groynes had been executed, and the consequent accumulation of sand and gravel had been so rapid, that the Spurn Point was already materially strengthened. It was the intention of the Government to complete the remainder of the groynes in the ensuing spring.

Sir Edward Belcher, in allusion to the danger to be apprehended from the removal of Spurn Island, said, that the true bearing of the Spurn Point from the dock entrance was about N. 63° E.; and on this bearing alone, the sea-wave would enter into the outer entrance,—that was, provided nature offered no other obstacles. He was one of the naval advisers of the late Mr. Rendel in 1850–52, and he found, by the later Admiralty Surveys, corrected up to 1860, that his views, as expressed in 1850-51, had been realised. He had then stated, that "for every foot you advance into the deep water, if carried obliquely—not stubbornly at right angles, in opposition to the tidal course, at half or three-quarters ebb—nature will accompany you by a deposit covering the channel, which would probably be scoured by the land-drains." From Mr. Calver's survey of 1851–

GREAT GRIMSBY (ROYAL) DOCKS.

Fig 1

CHART OF THE RIVER HUMBER, SHEWING SITE OF GRIMSBY DOCKS

Fig 3

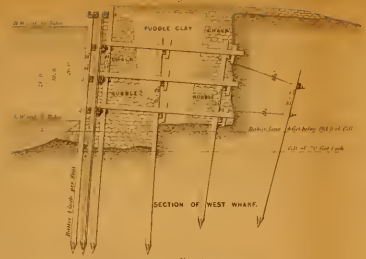


Fig 4

Fig 5

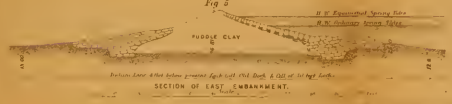
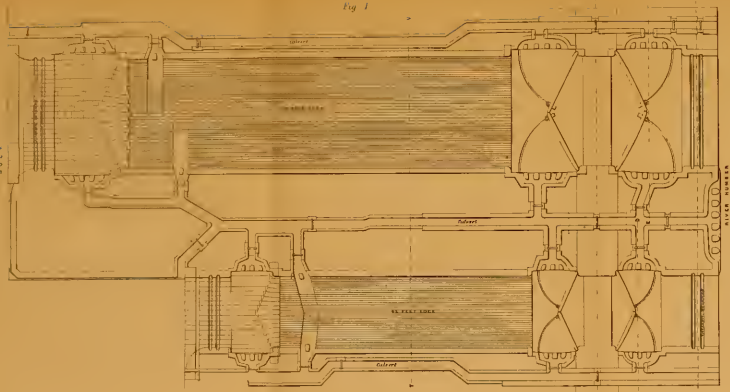


Fig 2

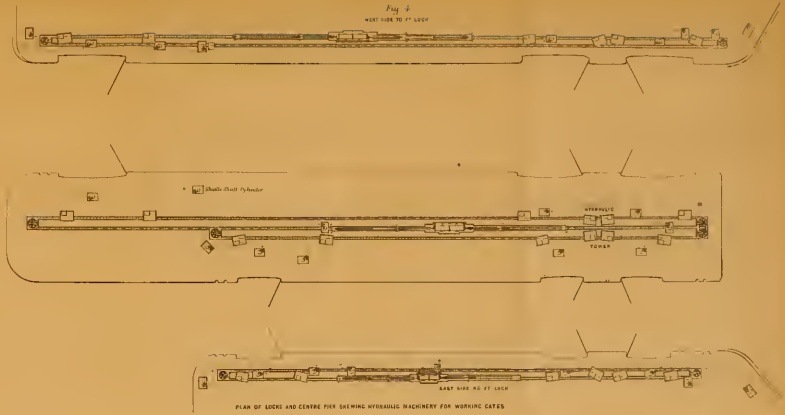
GENERAL PLAN OF OLD AND NEW DOCKS

Fig. 1



PLAN OF LOCKS SHEWING GATES AND SLUICES

Fig. 4



PLAN OF LOCKS AND CENTRE PIER SHEWING HYDRAULIC MACHINERY FOR WORKING GATES

Fig. 2.

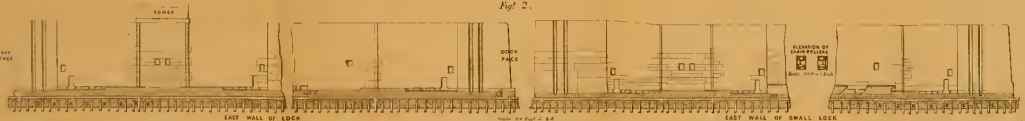
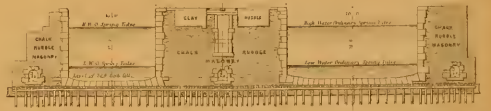


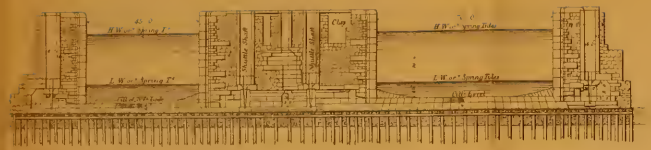
Fig. 3



TRANSVERSE SECTION OF LOCKS A B

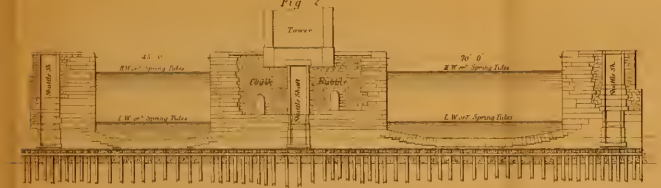
GREAT GRIMSBY (ROYAL) DOCKS.

Fig 1



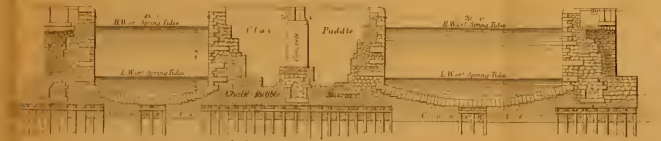
TRANSVERSE SECTION C D E F THROUGH LOCKS

Fig 2



SECTION G H THROUGH LOCKS

Fig 3.



SECTION T V THROUGH LOCKS

Fig 7

ELEVATION OF WEST WING WALL.

Fig 8

ELEVATION OF EAST WING WALL

Fig 9

SECTION ON L M

Fig 10

SECTION ON N O.

Fig 11

SECTION ON P Q

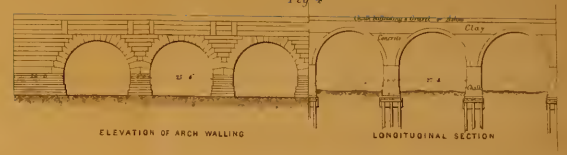
Fig 12

SECTION ON A S

Scale

SECTIONS OF EAST & WEST WING WALLS.

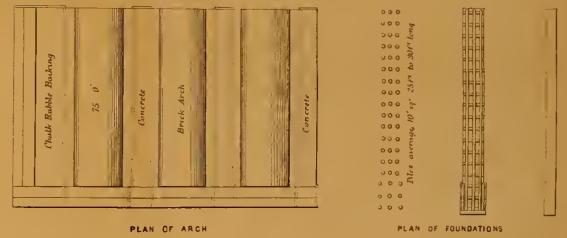
Fig 4



ELEVATION OF ARCH WALLING

LONGITUDINAL SECTION

Fig 5



PLAN OF ARCH

PLAN OF FOUNDATIONS

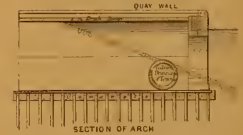
Fig. 13.

SECTION ON T V

Fig 14

SECTION ON W X

Fig 6



SECTION OF ARCH

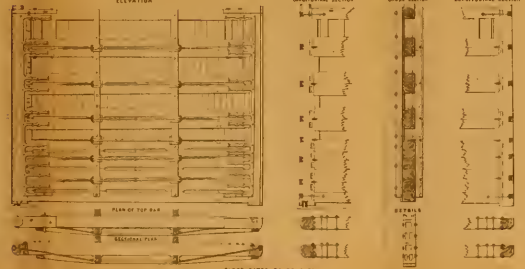
SIDE ELEVATION

END ELEVATION

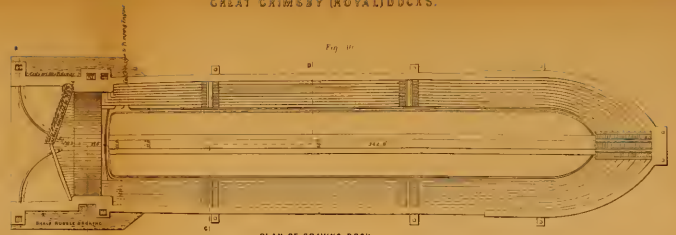
PLAN OF ROLLER FOR 70 FEET LOCK GATES

ANCHOR OF 45 FEET LOCK GATES.

ANCHOR PLATES FOR LARGE AND SMALL LOCK GATES



FLOOD GATES OF 70 FEET LOCK



PLAN OF GRAVING DOCK.

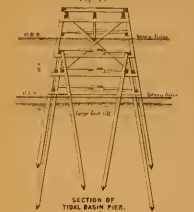
LONGITUDINAL SECTION.

SECTION ON A B

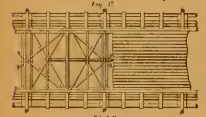
SECTION ON C D.

TRANSVERSE SECTION OF PIER AT ENTRANCE TO FISHING CRAFT DOCK.

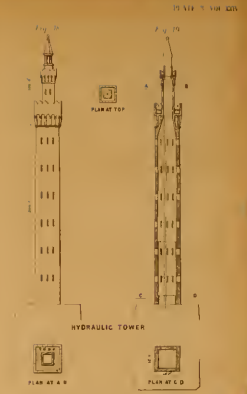
SECTIONAL PLAN



SECTION OF TIDAL BASIN PIER.



PLAN



HYDRAULIC TOWER

WAREHOUSE SHEDS

52, he perceived that in the interval of eight years, namely, from that date to 1860, the low-water line had advanced northwards on the western pier side about 500 feet; but on the eastern it had advanced no less than 900 feet. The line of pier had been carried out 3,000 feet. If it had been commenced 4,200 feet more westerly, and then carried to its present point, about 5,600 feet from the shore, the western extension of the low-water line would have now projected 1,500, or perhaps 2,000 feet, thus affording still greater security; and, moreover, as that bank had silted up to a distance of 6,000 feet, it would have now, under the conditions which he then proposed, have had a continuous extension to the end of the elbow, which would have been found in an easterly direction for the distance of about $2\frac{1}{2}$ nautical miles. The land gained within the triangle for timber float or storage would have then yielded an area of more than 191,100 square yards, and the cost would not have much exceeded the present outlay, seeing that the outer space would have needed only ordinary piling to oppose the sea for a term of years, and nature, in her convenient time, would have advanced the bank seaward. Long experience had convinced him, that wherever sudden steep coast lines existed, such as those at the Spurn, and at Hurst Castle, near the Needles, that no material change need be apprehended. It might be asked, what would be the natural result, if the mass of matter composing the Spurn were removed? He would answer, that the very force which caused its removal would operate in such a manner as to place it somewhere in the direction of the force exercised. The forces which would thus act, he would assume to be those of the wind, water, and tide from a N.E. to an E.N.E. direction; as those forces were greatest about and previous to the periods of high water, the flood-tide would be an accessory in the removal of the suspended or translated matter inwards. Hence it must be conceded, that the demolition of Spurn Island would merely prove a kind of removal of the matter of which it was composed, and that the Bull sand, or more probably the Clee-ness sand, would be elevated into the river. The Yorkshire coast would thus lose, and the Lincolnshire coast would gain territory. So that even assuming the apprehension of the Author to be verified, the task of the Engineer would be to help, and not to oppose nature. The river would thus be improved, and the Grimsby Docks, instead of being jeopardised, would be better protected, and would possess a much more valuable anchorage off its dock-mouth. With this view of the case, it was his firm opinion that the partial removal or breach of Spurn Island, by taking away an impediment to the free course of the river, would prove not to be a misfortune but a benefit. He would mention two lines of channel offering important advantages over the present tortuous navigation, which

was very difficult in bad weather, and not practicable by night at all times of tide. First, it would be an advantage if a channel could be forced in a line from No. 5 Buoy to the Kilnsea Warren Gap; there would then be a depth, on one straight line, free from every danger, at low water, of 22 feet near the coast, deepening to 42 feet at the outer edge of the bank, and such a channel could be used without the aid of a pilot, both by day and night. Secondly, supposing a breach to be effected where it was now feared, a channel from No. 5 Buoy would probably have a depth of 18 feet at low water, at 2,500 feet from the coast-line. The off-lying shoals of the Middle Bank would then, most probably, eventually replace Spurn Island, and within the bank so formed, secure riding ground, or shelter from easterly gales, might be found until the weather, or daylight, facilitated entry by the new channel. It would be undesirable to oppose the natural action now at work, as the materials of the works might be swept away as often as placed. It would be wiser to construct solid defences within, upon the assumption that the débris thrown in would form a solid 'glacis' to the inner structure. Any attempt to protect the coast-line, by works outside the shore-line, would, in his view, be very injudicious. The scale of tides annexed to the plan of the Humber showed, that the lines of action, during the whole course of the external flood-tide, were tangental to Kilnsea warren bend, and consequently did not press on Spurn Island; but on the contrary, their action would rather tend to silt up that foreshore. A comparison of the changes which had taken place in the estuary, extending over long periods, proved, that the alternate breaching and silting-up had been influenced by operations carried on within the river; and upon the whole it was obvious that money, under competent engineering advice, judiciously and liberally applied, might make the Humber a much more important river, not only for commercial but also for national purposes; indeed, the cause of humanity might be greatly advanced, as, if the changes he had indicated could be effected, that which was so much required on the eastern coast would be obtained, namely, a capacious place of refuge, which through a channel free from danger would, by day or night, and under all circumstances of weather or tide, be accessible to vessels seeking shelter without a pilot.

Mr. W. A. Brooks said, that the increase of the sand-banks, below the entrance of the tidal-basin of the Grimsby Docks, was simply caused by the inset of the current into the foreshore above the docks, and by an outset of the current, which formed a considerable eddy below the entrance of the basin. By these forces the triangular space above the docks was being gradually converted into dry land. As that took place, the shoal below would decrease, and finally disappear. In fact, from the nature of the

concave line of new shore which would be formed, the channel in front of and below the docks, would, at some future period, become deeper.

Mr. JOHN MURRAY said, that the cofferdam was an admirable structure, and had well answered the purposes for which it was designed. It would appear, however, that a very large quantity of clay had been used, the thickness of the cofferdam being about 7 feet on one side and 6 feet on the other, making together 13 feet in thickness, exclusive of the interior row of piles. He had constructed cofferdams in difficult situations, and had found it advisable to reduce the thickness of clay to a minimum, inasmuch as a large quantity did harm, from its tendency to swell against the piles. He had found, that 3 feet of clay puddle at high-water mark of the dam was as much as was necessary; and he preferred to batter the piles internally and externally, in order that the clay in the interior of the dam might subside equally on both sides. The middle row of piles in the cofferdam of the Grimsby Docks was for the purpose of preventing the water from running through at the tie-bolts. With two rows of piles as usually applied, the bolts had to pass through the dam, but there was a difficulty in preventing the water from running along them. He had however rectified that, by threading two loose pieces of plate-iron of 8 inches or 10 inches square through the bolt, allowing them to hang loosely thereon; those plates became buried in the clay puddle, and cut off any water running alongside of the bolts. He had also found it advisable to take away the interior walings as the puddle was brought up, but that necessity had been avoided, by putting horizontal straps of iron on each side of the inner row of piles, but still the walings were kept on in the inside of the outer and inner rows. The tendency of the clay was to consolidate, and in so doing it was arrested by the upper surface of the walings and created a vacuity below them. Any water therefore penetrating between the piles had a tendency to run a considerable distance along the interior of the dam, and there was great trouble in stopping it, from not knowing the exact locality of the leak. Where water had penetrated into the interior of a dam, he had often bored holes into the clay, and filled them with hydraulic mortar, and by that means stopped the leakage.

Mr. A. M. RENDEL said he had been, personally, very little connected with this work. Of the six engineers who were originally engaged in it, three were dead, and the Author was the only one who was now practising his profession in this country. With regard to the cost of the works, which was stated to be about £1,000,000, that sum included the purchase of the old docks and also interest of money for several years. When the greater portion of this work was finished, and the final contracts

were entered into, the estimated expense was under £600,000. Since that time there had been added a graving-dock, which cost £30,000 or £40,000, and a fishing-dock. The purchase of the Crown use in land had also cost £30,000. He believed the actual cost of the main dock with its entrance basins was rather more than £600,000. With regard to the filling up of the land on each side of the docks, that was nothing more than was to have been expected. Grimsby might be compared to a large groyne thrown across the foreshore. The result, as usual with groyning, was, that the land had been raised on both sides of the docks, and the water in front deepened, for there was now 3 feet more water in the sea channel in front of Grimsby than before the works were commenced. With regard to the basin, it was originally intended that it should be open, and that the tide should go through it; but, soon after the works were commenced, a heavy gale blew down one of the gates of the 45-feet lock. That was owing to the neglect of the men in charge of the work, who had left the sea-gates open until it was impossible, from the violence of the gale, to close them. Great alarm was caused at the time; and in order to afford shelter to the gates the sides of the jetties enclosing the basin were planked up, thus preventing the tide passing through them. The result was, a large accumulation of mud inside the basin. He was of opinion, that a portion of the planking might be removed without diminishing the shelter of the gates; but he believed the accumulation of mud was not considered an evil, and therefore nothing was done to remove it, beyond occasional dredging and scouring the channel leading up to the docks. In the original plan, protection from the easterly gales was to have been effected by the construction of a breakwater on Burcom, a bank in the channel of the Humber in front of Grimsby, but that intention was not carried out, from want of funds. From the same want, and from the nature of the site, the works generally were completed under circumstances of great difficulty. With regard to the mere exclusion of water from a cofferdam, that might be accomplished with a small amount of puddling. The dam at the London Docks consisted of only 6 feet of puddle; but in exposed positions mass was absolutely requisite. The cofferdam at Grimsby had to resist unusually heavy seas; hence the necessity for the three rows of piles, and for its great width.

Mr. Hawkshaw, Past-President, remarked that the Paper was a description of a great work. He agreed with the opinion, that the practice had been to make cofferdams of excessively large dimensions as to width. A dam had lately been made at Liverpool which was from 15 feet to 20 feet wide. He did not agree as to the advantage of sloping the piles internally or externally, he thought it was unnecessary; and he was of opinion that

4 feet or 5 feet thickness of clay was usually sufficient. He had lately had occasion to lengthen the Victoria Dock at Hull, and under circumstances of considerable risk, the end of the dock having to be cut away and the shipping to be maintained in 30-feet depth of water, by means of the dam, during the execution of the works. That dam was 500 feet long and only 5 feet wide. The whole of the shipping floated above it for a year and a quarter without accident. The result of that experiment convinced him, that no advantage was gained by the extreme width of cofferdams. The observations of Sir Edward Belcher were very important; but at first sight it was not obvious what benefit would have accrued, either to the docks, or to the navigation, by running out the groyne in the direction indicated. The opinion, that if the sea were to make a breach through the Spurn Point, the navigation of the Humber would not be obstructed but improved, might be entitled to serious consideration; the prevailing theory was, that the maintenance of the Spurn Point was important.

Mr. J. Scott Russell remarked, that he could bear testimony to the admirable manner in which the whole of the cofferdam work was carried out. He had prepared for the late Mr. Rendel, a design and estimate for a set of iron gates for the Grimsby docks. He was not, however, surprised that timber gates should have been adopted, for at that time, timber of the best quality was to be found at Great Grimsby so cheap, that there would have been a preposterous difference in price. The counterforts, he thought, were well adapted to give strength and support to the cofferdam, and to enable it to resist the strains to which it was subjected, through the great force of the sea in that particular position.

Mr. Clark in reply, said, that he questioned the correctness of the views expressed, to the effect that the navigation of the river Humber would be improved, by the formation of a channel between the Spurn Point and the Yorkshire main. He understood that it was proposed to form an artificial and regularly constructed channel through the promontory, at a point between the Spurn Point and Kilnsea; but he did not see the utility of that design: as there already existed a sufficient entrance to the Humber between the Spurn Point and the Bull sand, and if a new channel was formed north of the Spurn Point, the probabilities would be, as he had before expressed, that the channel of the river, in front of Grimsby, would, in a short time, be silted up.

It was well known, that there was a great deficiency of harbours of refuge on the east coast of England, and he believed, that from the Downs to the Frith of Forth, there was not one equal to the harbour formed by the overlap of the promontory of Spurn, known as the Hawke Roads. The promontory of the Spurn protected the anchorage from all winds, except from due south, and he had

seen five hundred vessels at anchor in those roads during heavy gales, even from E.S.E. Therefore, if it were only for that reason, he thought the Spurn Point should be protected.

The present entrance to the Grimsby Docks was perfectly accessible and convenient at all tides. Since the dock works and piers had been made, the increased scour of the ebb tides had deepened the channel immediately outside the piers 3 feet; therefore he did not see the advantage that would have been gained by carrying out the pier or breakwater, as the scour of the tide would not have been greater than it was at present. He believed, however, that it would improve the river, if the foreshore, within a line drawn from Stallingborough lighthouses to the piers of the Grimsby docks, were reclaimed, as the probable effect would be, that the Burcum sand would be almost, if not entirely, washed away. The inner edge of that sand had already been removed about 200 feet further from Grimsby since the formation of the dock works, although from the circumstance of the sluices having been placed at so low a level (namely, 6 feet below low-water mark) the effect of the scour was not so efficient as had been expected; the force of the water was sufficient to prevent the deposit of silt for a distance of about 150 feet from the face of the works, but beyond that distance the effect diminished, and the silt was then deposited in the form of a bar across the channel. This bar therefore, and the remainder of the channel to the pier heads, required to be dredged, scouring being of little use; when there was a head of 6 feet or 7 feet of water over the sluice holes, the quantity of water used for scouring was about 3,000,000 cubic feet. It was considered unadvisable to continue supplying the docks with fresh water, on account of the expense of working the pump: he believed that sufficient fresh water could have been obtained, even if the well had failed, as there were means provided for supplying the pumps with fresh water from the Clee drain, which could have been diverted into the large well.

Mr .Fowler, V. P., observed, that the Author's opinion, adverse to the formation of an opening through the Spurn Point, was entirely in accordance with his own views. As the primary idea of having fresh water was for the sake of the ships' bottoms, he would like to know to what extent the dock had silted up, since the pumping of the fresh water was discontinued.

Mr. Clark said, that the docks had silted up, since 1852, to the extent of 5 feet in depth, over about one-third of their area: the floor of the dock bottom was now kept to the proper level by dredging. The water was now obtained from the Humber; but it was in contemplation to derive the supply of fresh water from the old dock, by making a connecting cut, and at the same time to enclose a portion of the foreshore outside the old dock entrance, to form timber ponds, which were much wanted.

The banks on each side of the tidal basin were allowed to silt up, chiefly for the sake of narrowing the entrance channel, whereby the effect of the scouring was increased, and partly for the advantage of disabled vessels, which frequently run on to them, and after being caulked at low water, proceeded to sea again without incurring the expense of being docked. In fact, regularly constructed 'hards,' if formed on those banks, would be of great value for beaching vessels.

December 6, 1864.

JOHN FOWLER, Vice-President,
in the Chair.

The following Candidates were balloted for and duly elected:—Lieutenant-General EDWARD TODLEBEN, as an Honorary Member; ELIAS DORNING, ROBERT SAMUEL FRAZER, JOSEPH LOUIS GALLOTT, WILLIAM JOHN HARDCASTLE, GEORGE LATHAM, GODFREY OATES MANN, JOHN RICHARDS MANNING, JAMES SIMPSON, Jun., WILLIAM STOPFORD SMYTH, and OSWALD YOUNGHUSBAND, as Members; BENJAMIN CHAPMAN BROWNE, WILLIAM FONTAINE GOLDING BRUFF, CHARLES CAPPER, WILLIAM CRAVEN, FREDERICK LEWIS DIBBLEE, GEORGE HAY EDWARDS, EDWARD FRÄNCKEL, WILLIAM HARRISON, ARTHUR JACOB, B.A., WILLIAM HOME LIZARS, DAVID LLEWELLIN, CHARLES THOMAS LUCAS, THOMAS LUCAS, CALLCOTT REILLY, JAMES WEEKS SZLUMPER, and ALFRED AYSCOUGH WILKINSON, as Associates.

No. 1,115.—"Description of the River Tees, and of the Works upon it connected with the Navigation."[1] By JOSEPH TAYLOR, Assoc. Inst. C.E.

THE River Tees rises high up in the south-eastern flank of Cross Fell, in the Goredale series of carboniferous limestones, and not far distant from the sources of the Tyne and the Wear. It flows nearly due east through a deep valley, and passes, for the most part, through a wild moorland country. At the foot of this valley the river appears at an earlier period to have formed a lake, the bed of which is still visible, and is called the 'Wheel'—probably a corruption of Weald. At the lower extremity of the 'Wheel' the river forms the noble cascade of 'Caldron Snout,' where it falls over the great whinstone cill, which here attains nearly its maximum thickness; it then runs, for many miles, through the beautiful valley of Teesdale, still continuing its course through the whin cill, till at the 'High Force,' where the bed has been thrown down by a 'fault,' it again forms a waterfall: and still running through a beautiful country, passes the old town of Barnard Castle, and through the lovely scenery of the Rokeby district.

[1] The discussion upon this Paper extended over portions of four evenings, but an abstract of the whole is given consecutively.

This valley presents many local names, evidently derived from the Scandinavian mythology, such as the rivers Balder, Wodenscroft, Thorsgill, and many others—unmistakable evidence of the early occupation of the country by the Danes.

Having surmounted the whinstone barrier, the river flows through a more open valley, and intersects the upper beds of the Goredale series, the millstone grit series, and cuts through the magnesium limestone near Pierce Bridge. The remainder of its course is now through the sandstones of the new red formation, and the country is more open. Nearer to its mouth commences the liassic series, containing the valuable and extensive beds of ironstone of Cleveland. Recently a bed of rock salt has been discovered near Middlesbro', at the base of the upper new red sandstone.

Returning to the course of the river below Barnard Castle, and immediately above Darlington, are extensive waterworks, which supply not only this town, but Stockton-on-Tees, a distance of 12 miles, and thence to Middlesbro', 4 miles further. The water, which is pure and soft, but strongly peat-stained, from its moorland origin, is conveyed to Stockton through pipes laid along the Stockton and Darlington railway. Neither at these works, nor elsewhere on the river, have any gaugings been taken with sufficient accuracy to be of value.

About 5 miles below Darlington, at Yarm, a town of great antiquity, the river becomes tidal, and is navigable for small vessels: 7 miles lower down is Stockton-on-Tees. Here it assumes considerable dimensions, and vessels of from 200 tons to 300 tons burthen come up to its quays. From Stockton to Middlesbro', 5 miles, its course is very tortuous; and immediately below Middlesbro', after making a sudden bend to the north-east, it opens into a broad estuary, upwards of 3 miles in width from shore to shore, but of this a large area is only covered to the depth of a few inches at high water. The Bar Buoy is about 8 miles below Middlesbro'. The total course of the Tees is between 70 and 80 miles in length, and its basin contains an area of about 750 square miles.

Stockton has been, for many years, the outport to a large agricultural district, as well as the shipping place for the lead of Weardale and the coal of South Durham; the efficient navigation of the Tees has therefore been long a subject of importance to the inhabitants. As early as 1769 the local histories record, "that Edmund Harvey, a tradesman of Stockton, spent a long life-time in fruitless endeavours to improve the channel of the river between Stockton and Portrack." In 1791, Jonathan Pickernell revived the scheme, and proposed to make a cut 220 yards long for the moderate sum of £3,970 14*s.* 10*d.* In

1804, William Chapman, Civil Engineer, made a report upon the state of that part of the river and an estimate of the expense of the same cut. Finally, in 1808, an Act was obtained "For making a navigable cut from the east side of the River Tees, near Stockton, through the neck of land, into the said river near Portrack, in the county of Durham, and for making various other improvements in the navigation of the said river, between the town of Stockton and the sea." This Act was granted to a corporation, styled the 'Tees Navigation Company,' into whose hands the custody of the river was committed, with the usual powers to levy dues, &c. The cut, or channel, referred to, was opened in 1810. Its length was 220 yards: it shortened the course of the river about 2½ miles, and produced a scour, by which the depth of water at Stockton Quay was increased from 9 feet to 11 feet. The cost was upwards of £12,000. The tonnage of the port increased from 24,534 tons, in 1804, to 42,904 tons, in 1812.

The opening of the Stockton and Darlington Railway in 1825 effected a considerable increase of trade upon the Tees, by bringing the produce of the South Durham coalfield to Stockton, where the coals were shipped at staiths erected along the banks of the river. In 1828, the Tees Navigation Company obtained a second Act, empowering them to make another cut, from Blue House Point to near Newport, 1,100 yards in length, and to raise £20,000 in shares and £30,000 by a loan. The cost of this cut was about £26,000. The tonnage of the port, in 1828, was 87,823 tons.

The second cut was opened in 1830, and about the same time, the construction of timber-jetties, or groynes, at right angles to the course of the stream, was commenced. These groynes were erected at intervals, from the bridge at Stockton, to Cargo Fleet, and are of various lengths, from 40 feet to upwards of 2,000 feet, and several of them have been lengthened at different times. The total number, at the present time, is forty-three.

In 1830, the railway was extended from Stockton to Middlesbro', 5 miles lower down the river, and on the opposite or Yorkshire side. The railway was carried across the river, a little above Stockton, by a suspension-bridge, which was not, however, found sufficiently strong, and instead of carrying an engine and train of wagons, as intended, was unable to bear with safety the weight of more than two wagons. The traffic down to Middlesbro' was therefore principally worked by horses till the bridge was strengthened. A cast-iron girder bridge has since been erected.

Both at Stockton and at Middlesbro' the coals were shipped at substantial stone buildings, 30 feet to 40 feet high, running parallel to the bank of the river, and called staiths; and at right angles from these, stages projected into the river. The coal-wagons

were lifted to the required height by two powerful steam-engines, and were then distributed to the several stages, and lowered to the decks of the vessels by self-acting machinery. There does not seem to have been any advantage in this complication, of alternately raising and lowering the wagons, and the simpler plan of the perpendicular drop, has since been adopted at these ports. Gradually, the shipping berths at the staiths became so bad that a ship of the ordinary draught of water could with difficulty be unloaded, and in 1842 a dock, for the shipment of coal, was therefore constructed a little below Middlesbro', and the staiths on the river were abandoned.

In 1846, the tonnage of this port was 742,521 tons, which has not since been exceeded. In 1847, the opening of the West Hartlepool Railway and Dock, diverted a portion of the coal trade from the Tees; and a further decline in shipments ensued, from the consumption of coal in the manufacture of iron at Middlesbro', till, in 1850, the amount was only 452,237 tons.

The principal works in connection with the navigation of the Tees having now been generally described, it is necessary to point out their effect on the channel of the river. The first cut, of 1808, appears to have been well devised and efficient. Its length (220 yards) was small, compared with the distance saved to the navigation, and it was executed at the moderate cost of £12,000, including £2,000 for compensation for land. This cut appears also to have contributed to the removal of a troublesome shoal which lay a little higher up the river; and an increased depth of water, to the extent of 2 feet, was also produced at Stockton Quay.

The expediency of the second cut is more doubtful. The difference in length between the cut, and the bend of the river avoided is comparatively small; and as steam-tugs were, at this period, generally employed in towing the vessels between Stockton and the sea, the distance saved was immaterial. The first cut avoided a narrow and tortuous channel; the second destroyed a fine broad reach of the river; for the original channel, though left open at the eastern end, became at once the bed of a lake, and, gradually degenerating into a swamp, soon silted up, and thus deprived the channel below of an important reservoir of tidal water.

About the time of the opening of the second cut, the erection of timber-jetties or groynes was commenced, immediately below the bridge at Stockton. The combined effect of these groynes, and of the two artificial channels, has been to reduce the river, between Stockton and Newport, to a nearly uniform width, and to produce almost a straight channel, through which the ebb tide flows with considerable velocity; this, however, is suddenly checked at the eastern extremity of the second cut, by the greater width

of the channel, and the natural tendency is for all matters held in suspension to be deposited, and so to form shoals. To counteract this tendency, the system of groynes was continued lower down, but the same result, the filling up of the channel below, followed the construction of each successive groyne. As the river widened, so the difficulty of maintaining deep water was increased. From 1830 to 1852, by which time the resources of the Tees Navigation Company were exhausted, there seems to have been a constant struggle to secure a deep-water channel, which as continually receded. At Bamblet's Bight, where the width is considerable, the works are of corresponding magnitude, and advance nearly into the centre of the river, three of the jetties being upwards of 1,000 feet in length, and connected, from head to head, by sheet-piling. Where these jetties now stand there was, formerly, a deep-water channel, close in to the north shore; and the little town of Haverton Hill, lying in the Bight, was intended, by the Clarence Railway Company, as their coal-shipping station. At present, all the space comprised within the enclosure of the jetties is a vast area of mud, some of it only covered to the depth of a few inches, even at high-water spring-tides. The silting up of the north shore of Bamblet's Bight must have been contemplated when these works were designed; but, at the same time, their effect was to cause what could not have been intended, the filling up of the shipping-berths at Middlesbro', a little lower down on the south shore. Accordingly, in 1835, when the works in Bamblet's Bight had made considerable progress, a formal complaint was made by the Stockton and Darlington Railway Company; and Mr. Storey, the engineer to the Railway Company, made a survey of, and a report upon, this part of the river. When this was laid before the Navigation Company, they replied, "that he proposed such a departure from the general principles hitherto acted upon, that his plans could not be listened to."

For some time previous to the dissolution of the former body, the river below Middlesboro' had been in a very bad state, and was continually getting worse. In Mr. Bald's Report to the Admiralty, in 1851, he gives several letters from shipowners, complaining to the Clerk of the Navigation Company, of the state of the river. The following are extracts:—Dec. 18th 1849; "One day during the present week the pilots report, you could walk across the bed of the river near the ninth buoy, dry shod, with the exception of one part, about 8 yards wide, which was ancle deep." And again, March 28, 1851:—"Since you were here, the 'Jane and Ann' grounded in the South Channel. I annex you the captain and pilot's statement respecting it, which I believe to be quite correct. You will observe that there was

2 feet 11 inches more water on the dock cill than she drew, yet she grounded. At the same time, I believe she would have gone down had the buoys been properly placed. The Channel changes very much every spring-tide, by the operation of the jetties below Cargo Fleet, which would be pointed out to you when you were down the river." The Author is able to corroborate these statements, having found, at the same period, considerable difficulty in getting down the river at low-water, in a small boat not drawing more than 10 inches of water. At this time the whole of the timber groynes had been constructed, and no other works had been commenced; so that it may be fair to take the above statement as an index to the state of the lower part of the river under their operation.

The Tees Navigation Company appear, according to their final balance-sheet, to have expended, under the Act of 1828, £95,000, against capital £20,000, loans £30,000, leaving a deficit of £45,000. For some years previous to their dissolution, the navigation dues had been leased to the Stockton and Darlington Railway Company, who paid an annual sum of £8,200, to free the vessels loading in their dock at Middlesbro' from the tonnage dues, which were found to operate injuriously on the trade of the port.

The effect of the groynes seems to be nearly the same in all cases. The deposit from the river is rapidly collected within the extent of the groyne, and at length is only covered at high water spring tides; so that, in many places, vegetation has begun to form. The effect of this deposit is, practically, to advance the foreshore of the river to the extremities of the groynes, thereby reducing, in some parts, the width of the original channel of the Tees one-half, and, in consequence, a large amount of tidal water has been excluded. In proportion to the diminution of the tidal water is the reduced velocity of the ebb-tides, and the diminution of their scouring force, producing inevitably a corresponding result in the lower reaches of the river; and it has been seen, that the channel almost runs dry at low water, near the ninth buoy.

It will be interesting to compare this state of the river, with what it was prior to the construction of any works in the Channel. In an old chart of the Tees, corrected up to 1821, by Palliser Thompson, pilot, and a relative of the celebrated navigator, Captain Cook, it is shown that the least depth of water between Cargo Fleet and the ninth-buoy anchorage, at that time, was 6 feet, excepting upon the Mussel Scarp Shoal, since removed by dredging. It may therefore be concluded, that if this dredging had been done in 1821, it would have given a minimum depth of 6 feet at low water, previous to the expenditure of nearly £100,000 in works which have proved to be ineffectual.

Hence the evidence appears conclusive, that the effect of the works in the upper part of the river was to reduce the depth in the channel below Middlesbro' 4 feet; and, as a certain consequence of the withdrawal of such a large amount of tidal water, the strength of the ebb tides has also greatly diminished. When the coal-staiths were erected at Middlesbro', it was not considered safe for a vessel to ride at a single hawser, and it was necessary for the steam-tugs to wait the turn of the tide, or, at any rate, till the flood had slacked, before towing the vessels down the river. Now it is customary for the ships to leave the dock an hour before high water, or at the very strength of the flood, in order to secure the best of the water over the shoal places below Cargo Fleet, and no precautions are necessary in moving vessels: the deep-water anchorage-berths have also considerably diminished of late years. At 'Samphire Batts,' opposite the dock entrance, where, formerly, a number of loaded colliers could lie afloat at low water, much of the space is dry. The London steamer, if prevented from getting out to sea after she has gone down the river, is obliged to return to the wharf at Middlesbro'. In the reach below Middlesbro' the ebb tide is so sluggish during the last quarter, as to be scarcely perceptible.

It is not questioned, that the channel, between Stockton and Middlesbro', has been made more direct, and the depth more uniform, by the construction of the various works upon it; but it is to be inferred, from the previously-stated facts, that better results might have been obtained by a judicious system of dredging, and that the disastrous effects, upon the lower reaches of the river, might have been avoided. The jetties constructed below Cargo Fleet, to remove the shoal in the South Channel, do not appear to have had that effect; but, on the contrary, to have increased the evil. This shoal, which causes so much delay and expense to the shipping-trade, was stated to be 100 fathoms long, and to have risen 2 feet; it would therefore contain 14,000 cubic yards of material. According to Mr. Bald's opinion, "a powerful dredging-machine, such as No. 5 on the Clyde, with fifty punts, would, in good weather, remove this shoal in about fifteen days, filling one hundred punts per day, containing 10 cubic yards each. The 14,000 cubic yards, at 1*s.* per cubic yard, would be £700. But if the Tees Navigation Company had a steam-dredge there[1] of their own, properly wrought, it would not cost more than £350. Such a river as the Tees, and such a navigation, should have a powerful steam-dredge, to remove any shoals which might form in it; and, above all, works which cause shoals should be removed." Thus, the cost of removing the shoal by dredging, under the most favourable cir-

[1] The Navigation Company have not had a steam-dredge since 1837.

cumstances, was estimated at £350; whilst the cost of the jetties, which did not remove it, must have been many times that sum. In fact, the operation of dredging, by lowering the bed of the river, and increasing the tidal flow, acts in direct unison with the current, and assists its natural scouring forces; whilst the contraction of the channel, by jetties or groynes, shuts out a corresponding amount of tidal water, and weakens the scouring force of the ebb tide.

The present Tees Conservancy Commissioners, who had to undertake the charge of a river almost entirely denuded of its tidal water, and with the lower part of its channel reduced to a depth of a few inches at low water, have principally directed their attention to dredging the channel, and to the formation of groynes or training-walls, in place of the old timber-jetties. These groynes are composed of the slag from the ironworks, and are constructed, either at half tide, or at low-water mark. The channel, below Cargo Fleet to the sea, is now reported to be much more direct than it was in 1851, and to be increased in depth to upwards of 4 feet at low water. A breakwater, of considerable extent, formed also of iron slag, is now in process of construction near the mouth of the Tees, commencing at Tod Point on the southern shore, and extending across the Bran Sand to the chequered buoy, a distance of about 4,300 yards. It is intended to form another pier from the north shore, commencing at Seaton Snook, and extending over the North Gare to the first black buoy, about 2,000 yards. The ends of these two piers are to curve seawards, so as to form an entrance-channel, of about 600 yards in width. A lighthouse, 60 feet in height, is to be erected at the end of the South Pier.

During the present stage of the works, the slag-blocks are merely 'tipped,' and are allowed to find their own position. Each block weighs about 3 tons, and from 600 tons to 700 tons are deposited per day. Ultimately, it may be requisite to face the seaward slope, either with its own material, or with stone. The slag is run into iron 'bogies' at the furnace, to be carried on the railway, and is removed while hot, to prevent the disintegration of the blocks, by the vibration of the rails, and occasionally a block is still red hot when thrown into the sea. By constructing the piers of this substance, the cost will be less than it would be by the use of any other, as the ironmasters make no charge for it, but pay the River Commissioners, at the rate of $1\frac{1}{2}d.$ per ton for causing it to be removed. The Railway Company charge the Commissioners at the rate of $\frac{1}{4}d.$ per ton per mile for its carriage, and, as the average distance of the furnaces does not exceed five miles, the bulk of the material will be deposited in situ without cost. The durability of piers thus constructed, and their power of resisting the action of the sea, will be duly tested in course of time; it

would be, at present, premature to hazard an opinion as to their effect, and that of the training-walls upon the entrance and channel of the river. When these works are completed, the river will be entirely changed from its original features, and will require a treatment suitable to its new character; but it is hoped that the construction of these piers will form a safe and sheltered harbour of refuge at the mouth of the Tees, and confer an incalculable boon upon the shipping, on that iron-bound and stormy coast.

The present depth on the bar, at low-water spring tides, is about 11 feet, and 27 feet at high water; a greater depth than exists on the bars of the Tyne, the Wear, or the Clyde. The harbour has been considered the safest between the Frith of Forth and Yarmouth Roads, and very few vessels are lost in entering. On the 30th March, 1850, sixty-eight sail of ships came in, in one tide, with a heavy gale from the south and south-east, and a strong sea, without loss or casualty. Pilots and ship-masters say, "they never refuse the Tees in the most stormy weather, or in the darkest nights, provided there is no fog to obscure the beacon lights." It is in general well buoyed and lighted, the jurisdiction of the Trinity House extending up to the anchorage at the ninth buoy.

It is scarcely necessary to enlarge upon the importance of obtaining and preserving a deep-water channel, from the sea to Middlesbro',—the centre of a district, that promises to rival any part of the kingdom in the production of iron; but the state of the river is a serious drawback to its growing prosperity. At the present time large quantities of manufactured iron, destined for India, Australia, and other parts of the world, are sent at great expense and loss of time to Hartlepool, the Tyne, and the Wear, for re-shipment in vessels, that are prevented from coming into the Tees by the want of water. It will manifestly be a serious calamity, if with the great natural advantages possessed by the River Tees, it should be found beyond the range of engineering ability to secure a channel of sufficient depth to answer the requirements of the port. On the Clyde, the cut through the Port Glasgow bank, which is the key to the navigation, gave an increased depth at the channel entrance, of about 6 feet, over a length of more than half a mile. The same increase of depth, in the lower channel of the Tees, would open the port of Middlesbro' to vessels of the largest class, and there is no reason why it should not be obtained by the means which have been so successfully employed in the Clyde.

The Paper is illustrated by several diagrams and large maps, some of which have been lent for the purpose by the Tees Conservancy Commissioners, who have allowed reduced copies to be made, from which Plates 4 and 5 have been compiled.

[APPENDIX.

PLAN OF THE RIVER TEES.

Surveyed by J. K. Culver R.N.

FROM CARGO FLEET TO TOD POINT.

THE RIVER TEES.

LONGITUDINAL SECTION FROM STOCKTON BRIDGE TO THE BAR FROM RIVERS SURVEY OF 1883

APPENDIX.

During the twelve months ending 31st October, 1864, there have been deposited at the South Gare breakwater 210,537 tons of slag, and 2,745 tons of ballast, the distance advanced during that period being 1,000 feet. The width of the breakwater is now 65 feet at the top, and its height is 30 feet above low-water mark.

The sea slope is 90 feet, and the river slope 40 feet, or 1 to 3 on the seaward and 1 to $1\frac{1}{3}$ on the river side. As the material is deposited, it assumes a slope of not more than 15° or 20° from the vertical, until the first heavy sea occurs, when the sea slope is lengthened out by the washing down of the material from the top. This being made up, is again partially washed down, but being replaced, it has seldom had to be made up a third time.

One hundred yards from the end of the breakwater, where the work has become consolidated, the storms have never done any damage. The sea slope has been firmly set by the action of the waves, and so far as the work has yet gone, no further paving is necessary.

No appreciable settlement has taken place after the permanent rails have been laid, the slag seeming to find its bed shortly after being deposited,

Since the edge of the swatchway was reached, the depth of water in front has been at times 9 feet, 10 feet, and 15 feet at low water, while, at other times, the firm sand has extended in front of the slag for a considerable distance; and it was uncovered 30 yards beyond the slag during the month of November, 1864. The work is not advanced during storms, as the loose blocks are then tossed about by the sea and carried inwards; at first they were laid upon the river side, afterwards principally on the sea side; but the last heavy storm carried the material again to the river side of the works.

The quantity of material deposited during the month of November, 1863, from nine furnaces, was 10,185 tons; the quantity deposited in November, 1864, from twenty-five furnaces, was 24,858 tons. The work is now being proceeded with night and day.

[Mr. W. A. Brooks

Mr. W. A. Brooks said, that in 1828, he was appointed Resident Engineer to the Tees Navigation Company, under Mr. Price, and the works executed extended from Stockton Bridge to Cargo Fleet, the commencement of the estuary, a course of about 7 miles. At Bamblet's Bight, where the channel was deep and tortuous, and the shore concave, he had made several small jetties, for the purpose of gradually warping up the bight. Very little was then done in the estuary below; but, in the years 1829 and 1830, a cut was made, commencing at Blue House Point, where the cut of 1810 terminated. It was 1,100 yards in length, extended eastward, and avoided a considerable bend. Its immediate effect was to add from 2½ feet to 3 feet of depth in the navigation to Stockton, and to enable the spring tides to rise from their former height, of 8 feet and 9 feet, to the height of 11 feet and 11½ feet. The cost was £24,000. No new shoals were formed by the execution of the works: on the contrary, the shoal alluded to in the Paper, as having been carried away by the cut of 1810, was not really removed till 1830, when three small jetties were constructed on the concave shore, and from 4 feet to 5 feet water was thereby gained. Had the gradual contraction of the river been made to end in a wide reach, of a straight form, the supposed deposit of silt might, probably, have accrued; but in the present case the current was discharged into the natural concave channel immediately below, and there was therefore no lodgment of material. That the river navigation was not injured by the groynes, or jetties, appeared from the circumstance, that in 1828, the shipping trade of Stockton was carried on by schooners, of from 100 tons to 120 tons burthen only, and that vessels of even that small class were forced to bring up at spring tides at Portrack, about half-way between Stockton and the estuary, and, at neap tides, at Cargo Fleet, to discharge half their cargoes into river barges, while at the present time, as was admitted in the Paper, vessels of from 200 tons to 300 tons burthen came up to the quays at Stockton. At Middlesbro', the shipping berths had not filled up in consequence of the works executed by the Tees Navigation Company. There never had been deep water at that part of the river, and there existed a sandbank, 100 yards in breadth, in front of the site chosen by the Stockton and Darlington Railway Company for the erection of the staiths; in fact, a considerable improvement had been effected, by compelling the current, after leaving Bamblet's Bight, to impinge upon the Middlesbro' shore, and thence to be deflected to the northern side of the river; deep water had thus been obtained at once. He could not approve of a system of mere dredging for the purpose of deepening the channel of the Tees: he was convinced that that system would be ineffectual. He had, however, employed a process

of alternate dredging and mining for the removal of two banks of hard red clay, one of which was situated at the east end of the cut of 1830, the other, below the termination of the works at Cargo Fleet. It had been stated, that previous to the works constructed by the Tees Navigation Company, the depth of water in the estuary was about 6 feet, but on reference to the engraved charts, he found, that in 1789 there were several shoals of 4 feet; and that one shoal, called the 'Outer Stones,' which traversed the channel at the ninth buoy, and which never changed, had only 3 feet; if it had less than that depth at the present time, it was to be supposed that the water ebbed out lower than it did formerly, and this would show a greater influx of tidal water. The depth on the bar was stated to be now 11 feet, but in the years 1789, 1805, and 1839, it was shown by the charts to be only 6 feet; therefore, according to the Author's showing, the bar had now nearly double the depth that it formerly possessed.

He believed that the slag pier now constructing on the South Gare and Bran Sands would make this danger permanent, for the South Gare varied in direction from west of north to nearly west and east, and the proposed pier would give it a fixed direction of from S.S. West, to N.N. East, and cause it to extend yet more under the lee of the Long Scar Rock, abreast of the Seaton shore, and there the bar would have less depth of water.

There was another point to which reference must be made, in order to remove any unnecessary apprehensions, as to a supposed abstraction of tidal water. The Author had stated that the bar had now a depth on it of 11 feet; but the chart of 1789 showed that there was then only a depth of 6 feet. In the engraved chart of 1805 the depth was still 6 feet, and the late Capt. Hewett, one of the hydrographers of the Admiralty, recorded, in 1831, only 6 feet on the bar. In 1839, Mr. Brooks made a survey of the sea-reaches of the Tees, which was published by the Conservators under the authority of the Admiralty, and that chart also showed only 6 feet on the bar. If the statement were correct, that there had been a great loss of tidal water, the strange deduction would have to be made, that this had done good rather than harm, since it was alleged in the Paper that the bar had now on it a depth of 11 feet, or nearly double its former depth. But, he thought, that depth was rather exaggerated.

There was another interesting circumstance connected with this bar, as deduced from the various charts he had exhibited, viz.—that whether the sea-reach debouched west of north, or even from nearly west to east, there was still the same depth of water on the bar. When the river took the more northerly course to sea, it was, as regarded navigation purposes, in the worst pos-

sible direction. Any nautical man must at once perceive, that for the sea reach to take a course, running as it at times did, so as to actually debouch west of north, vessels entering, or leaving, were exposed to the stroke of a beam sea in on-shore gales of wind, which was a most dangerous position, and that was why Admiral Sir E. Belcher, in his observations in reference to the Humber,[1] alluded to the advantages which would accrue to that river if the outlet were more direct. The sea-reach of the Humber was from north-west to south-east: if it could be changed to an easterly direction, it would be a harbour of refuge in every sense of the word, because there were 30 feet at low water at its mouth.

The Author thought it would have been better if, instead of the contraction of the river Tees by jetties, a judicious system of dredging had been adopted, by which he supposed the disastrous effects of the abstraction of tidal water might have been avoided. But to have attempted to deepen such a river as the Tees by merely dredging operations, would have been a Sisyphean labour, and would have required inexhaustible funds.

With respect to the slag-work at the mouth of the river, referred to in the Appendix to the Paper, he held that that work, described on the large plan by a pier on the South Gare and Bran Sands, would perpetuate the evil of vessels being exposed to be struck by beam seas, which was the case when the sea-reach debouched so much to the north. When the South Gare, which now varied in its direction from west of north, to at times as far as from west to east, was made, by the proposed slag and rubble pier, permanently to debouch in a direction from S.S. West to N.N. East, the tail of the present South Gare would go on extending beyond it, till the South Gare got more under the lee of the Long Scar Rock abreast of the Seaton shore, and there the bar would become shoaler. The natural course at the mouth of the Tees was thus: at one period the river debouched with an easterly outlet, but gradually it had worked round so far, as to have an outlet even west of north; and the channel formed between the North and South Gare Sands was thus of course greatly increased in length, until at last it broke out again in a shorter direction to the eastward, between the Bran Sand and the shoulder of the South Gare Sand, or where the latter joined the Bran Sand, and then gradually turned until it had, as before, a nearly northerly outlet.

Mr. John Murray said, he had been acquainted with the River Tees since the year 1836, when he was employed as Engineer, to carry into execution a plan devised by Mr. Price, C.E., on behalf of the Tees Navigation Company, and by Mr. Leather, C.E., on the part of the Stockton and Darlington Railway Company. Cer-

[1] *Vide ante*, p. 51.

tain lines were delineated on this plan for the improvement of the river between Bellingham Reach and Cargo Fleet, so as to give deep water at the coal staiths of the Stockton and Darlington Railway Company, on the Yorkshire side of the river, and at the Clarence Railway staiths, on the Durham side.

In accordance with this plan, he had lengthened the central and two other jetties 400 feet, 98 feet, and 68 feet respectively, adding to the central jetty a breastwork 692 feet in length, and to the jetty below it a breastwork 520 feet in length; he had also lengthened two jetties on the Yorkshire coast, 158 feet and 118 feet respectively; he had shortened one jetty, adding a breastwork 366 feet in length on the lower side of it; and had constructed three new jetties: the first on the Yorkshire side of the river, 268 feet in length; the second on the Durham side, 468 feet in length; and the third, opposite to the latter, 358 feet in length.

These works, executed in 1837 and 1838, caused the channel to be diverted into its new course. From soundings, taken in 1840, it appeared, that the depth of water had been considerably increased; but in place of the river on the south side taking the line intended by the plan, a spit had been formed, as shown by the dotted lines in Plate 6, indicating the necessity of joining two of the breastworks, so as to produce an uniform course to the river, and thereby reduce the sand spit. These jetties and breastworks together, all of simple construction, cost between £5,000 and £6,000, and were fully shown in a book of drawings, from which Plate 7 was compiled.

With regard to the improvement of a river generally, and the comparative advantages of jetties and longitudinal training-walls, it was exceedingly difficult to state, at what distances apart longitudinal walls ought to be placed, in the channel of a river. The Engineer would have to ascertain, by observation extending over a lengthened period, the quantity of water that came down in dry weather, and also the discharge in floods: on the one hand, he must not, by building these walls too near to each other, make the river too contracted; and, on the other hand, he must not place them so far apart as to do mischief by causing sand-banks. But with the system of jetties, simple in construction, in which inferior and inexpensive timber could be used, the Engineer was enabled to reduce, or lengthen them, as circumstances required; making the upper surface level with high-water at the banks, and about half-tide high at their extremities. When the river by such means was partially scoured, then was the time to construct the longitudinal half-tide training-walls, or breastworks to the jetties themselves, in order to remove any shoals which might form between them.

No reference had been made to the improvements at various

times contemplated in the estuary itself. It would be found, that Mr. Brooks had not only proposed to jetty the river, from Stockton to Cargo Fleet, but also downwards through the estuary, and to run out a pier from Seaton Snook, across the bar, in an easterly direction.

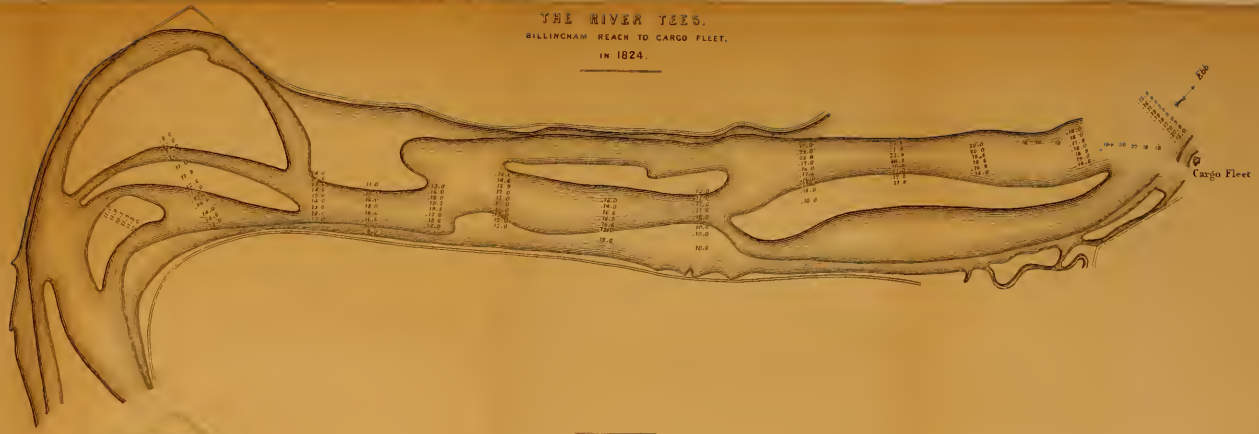
It had also been in contemplation to make a harbour of refuge at Redcar, and a ship canal from Cargo Fleet to that port. He had doubts as to keeping open such a harbour; for the ledges of rocks were covered at half-tide, and there was deep water between them. Therefore any matter in suspension would naturally be thrown over these rocks by the waves, and be scoured out again to sea, on the ebb. Whereas, if solid works were raised upon the outer rocks, so as to make the water quiescent, a deposit would take place between them, and in time fill up the harbour. It would therefore be desirable to take advantage of these ledges of rocks, for the purpose of jettying the north shore as far as the estuary; and he had ascertained by boring, that these rocks were continuous with the stone, which cropped out in the channel of the river. Hence, by placing dams across the proposed channel at both ends, removing the rocks through Tod Point, and using the material so obtained, as a barrier against the sea, a new channel might be formed for the water of the Tees, from Cargo Fleet to Redcar. It would be necessary to run out a jetty from the Durham shore to unite with this channel at the 'stones;' keeping open the existing channel to allow a free navigation, while these works were in progress. When the channel was excavated to its proper depth, and the Durham shore jetty was sufficiently strengthened; then, by the removal of the dams, the water might be enticed to take its course through the new channel to Redcar. By closing up the gap between the Durham side jetty and the 'stones,' a great part of this estuary, comprising upwards of 5,000 acres, would, in course of time, be warped up and reclaimed; leaving between 2,000 acres and 3,000 acres area of the estuary to remain as a receptacle for tidal water. He was of opinion that Redcar was a better outlet for the Tees than that which now existed, or than the one it was proposed to make by means of the piers at its mouth.

Mr. Brooks explained, that seeing the estuary was so tortuous, and that the works would be necessarily very expensive, he thought the best plan would be, to form a ship canal from Cargo Fleet to Redcar, with proper sea locks, so that they would have a deep water outlet with no possibility of a bar: whereas if the plan had been carried out, of forming a new channel for the Tees between Cargo Fleet and the deep water outlet, between the Salt and East Scar Rocks at Redcar, where there was now 30 feet at low water, the certain result would have been to transfer the bar of the Tees to Redcar.

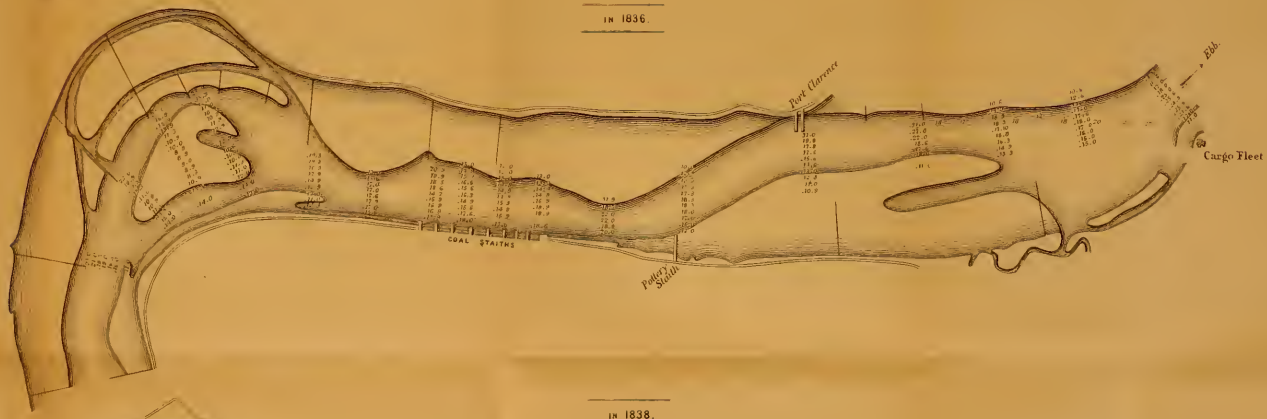
THE RIVER TEES.

BILLINGHAM REACH TO CARGO FLEET.

IN 1824.

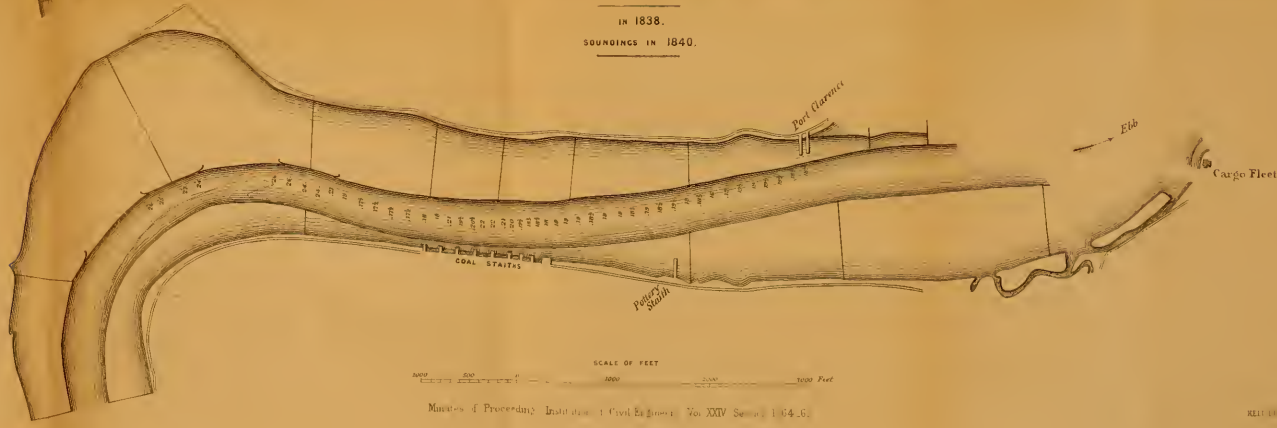


IN 1836.



IN 1838.

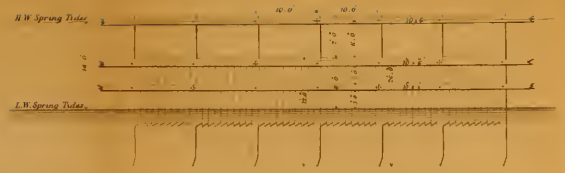
SOUNDINGS IN 1840.

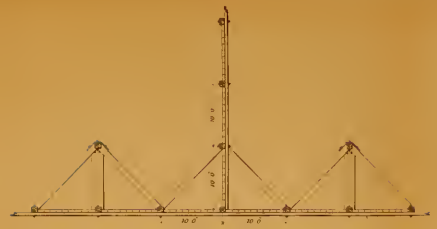


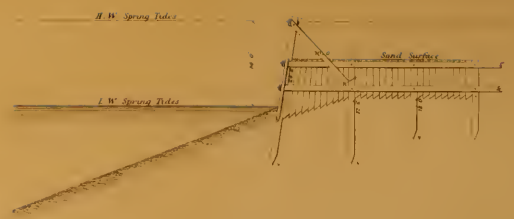
SCALE OF FEET

THE RIVER TEES.

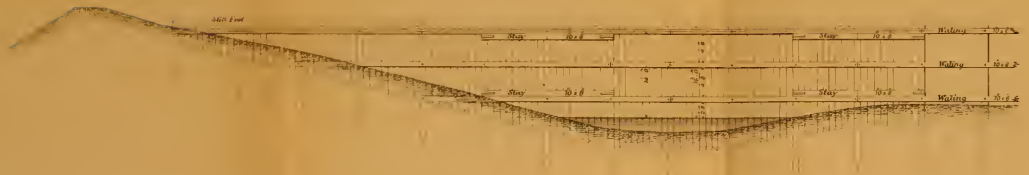
BREASTWORK OF JETTY IN RAMLETS BIGHT.

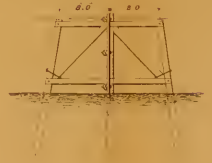


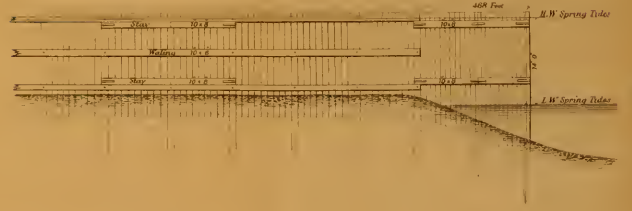


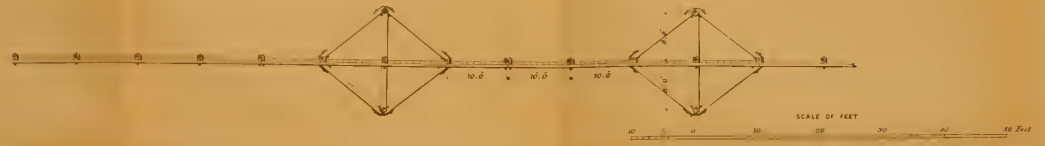


NEW JETTY ON THE DURHAM SIDE OF THE RIVER OPPOSITE TO THE POTTERY STAITH.









Mr. ABERNETHY said, jetties were sometimes useful to save the work of excavation, and to divert the current of a river into a given direction; but when allowed to remain as permanent works, as was the case in the Tees, and in the Dee, at Chester, the effect was injurious, by obstructing the tidal ebb and flow, and deflecting the current of the river. This deflection was the cause of the formation of holes at the points of the jetties, and of shoals between them, and thus the equalisation of the sectional area of the channel, or of the velocity of the current, was prevented. Jetties should therefore be regarded, in all cases, as temporary works. The system pursued at the Clyde was to connect their ends by parallel walls, and so virtually to abolish the jetties. In the improvement of the lower reaches of a river, the object to be aimed at was, to compensate for the decrease in the velocity of the current as it approached the sea, by an increase of volume and depth. For that purpose, dredging, in many cases, was useful, and should be especially resorted to for deepening the low-water channel where tidal water had been abstracted by closing up indents in the shore. That system had been lately pursued by Mr. Ure in the Tyne to a great extent, and with beneficial results. Without dredging, the improvements in the Clyde, particularly at its embouchures, could not have been effected. In general, the system pursued in that river was, first, to define the low-water channel by temporary walls or groynes, and afterwards, to maintain the intended width by training-walls. Taking into account the contraction of the channel leading up to Stockton, he thought that the lower part of the river approaching the sea was too wide between the training walls, and that there would not be a sufficiently continuous column of ascending, or descending tidal water to maintain a low-water channel of that width.

Mr. E. LEADER WILLIAMS, Jun., remarked that, comparing the effects of the different treatments of the Clyde, and of the Tees, the system of training-walls must be superior to that of jetties. It was desirable to gain as much tidal water as possible, in order to increase the velocity of the ebb. Cross-walls, or jetties failed to produce that result, for while the channel was contracted, both the flow and the ebb of the tides were impeded; and any advantage gained at the end of the jetties was at the expense of the channel in general. In all rivers, the hydraulic mean depth should be augmented as far as was practicable; in non-tidal rivers, by means of weirs, and in tidal rivers, by training-walls and by dredging. The increase of velocity in the tide when passing over deep water, instead of over sandbanks and shallows, was remarkable. In the Severn, during the ordinary low state of the river, the velocity of the tidal wave was four miles per hour; but if flood-water was running down at that speed, the tidal wave

flowed over it at the rate of ten miles per hour. Every foot of water added to the channel by deepening the bottom of the river, was effectual for scouring purposes at neap tides, as well as at spring tides, but the surface-water gained at spring tides was not so effective as that gained by dredging. No general rule could be laid down for the breadth of the channel, but if numerous cross sections were taken, if observations were made upon the effect of tides over a long period of time, and if the amount and velocity of the flow of the land-water were accurately calculated, it would be possible to obtain correct data, not only for the due width of the channel, but for the correct lines of the training-walls. He thought that training-walls were sometimes made too high; that, as a rule, their height should be about half-tide, and that the material should be suited to the site. The rubble-walls on the Clyde had, in some places, failed, being constructed upon a shifting foundation, and the scour being greater on one side of the channel, than on the other. Fascine embankments, which had been extensively used on the Severn, and on the Great Northern Railway works between Lincoln and Boston, were cheap and efficient. When bound together, and filled in with sand, the fascines formed a solid mass which firmly resisted removal, and sank vertically and remained strictly in line under the effects of the scour,—advantages not possessed by rubble masonry. A successful application of that kind of work had been made at Tewkesbury, where the Severn was wide. It was required, within twelve hours, to close the old channel of the river by an embankment of timber and earthwork, to raise the water, throw it over a weir 6 feet in height, and open the navigation through the new channel. Main piles were driven, with struts at the back, the sheet-piling and earth-backing being left till the last; but the piles had not been driven to the requisite depth, and the embankment yielded to the force of the river and gave way. To repair this disaster, trenches were cut in both banks of the river, in order to obtain a good land-tie, and then fascines, weighted with rubble and clay, were sunk. The fascines were placed across the stream in a V form, so as to withstand the pressure in the centre, and the embankment thus formed resisted the velocity of the current. He thought that system of embanking might be extensively employed in river improvements.

Mr. Ralph Ward Jackson said, it was certain that a great decrease in the depth of water between Stockton and Middlesbro' had been the consequence of the construction of the cross-jetties, and of the filling up of the intermediate spaces by mud; and that, although the channel had been straightened and narrowed, yet the river had continued to shoal, even below Middlesbro'. It was a very serious consideration, how far the entrances of tidal rivers

ought to be contracted by piers such as were being constructed at the Tees and at the Tyne. By these means, and by dredging, it was practicable to lower the bar, and to increase the depth of water over it, but not without, at the same time, so increasing the force of the ebb tide as to injure the navigation. It was to this cause that the loss of the steam-ship, the 'Stanley,' was chiefly to be attributed. She had got over the bar of the Tyne when there was deep water; but the ebb tide, running at the rate of from 5 knots to 6 knots per hour, forced her head round, and brought the ship broadside to the heavy following seas, which soon overtook her. The entrance of the Tees was from 2½ miles to 3 miles in width, more than twice the width of the Tyne, and the whole pressure of the North Sea bore in upon the flood tide. If this width were contracted to 1,800 feet, no vessel could, with an on-shore gale of wind, stem the tide, and enter the river with safety after the turn of the tide on the ebb. Another result of the contraction of the entrance would be, that the flood tide could no longer flow up to Stockton as before. A similar effect had followed the contraction of the mouth of the Tyne. The amount of tidal water, at the town of Newcastle, was thereby lessened, for it was not possible that the same quantity of water could pass into the river. He also feared, that by the exclusion of tidal water, the Tees bar would be increased, because, in rivers which depended upon the combined action of freshes and ebb tides for keeping down the sand, an accumulation must follow dry weather, if there was any deficiency in the scour of the ebb; and he had known the bar of the Tees to be covered at such times with no more than from 2½ feet to 3 feet of water.

For the purpose of fixing the channel of a river in a given direction, diagonal jetties possessed the great advantage of offering no obstruction to the flow of tidal water, except over the small space they occupied, and of causing no accumulations between the intermediate spaces. Their effect upon the ebb, which was more important than the flow, was to direct all the water between the groynes, in a natural manner, into one defined channel, and to accumulate it, to such an extent towards the bar, that considerable velocity was obtained, without the bad effect arising from the contraction of the entrance by piers. He did not think, that the Tees could be made available as a harbour of refuge. Such a harbour should afford access at all times, both at flood and at ebb, and vessels must be able to anchor, without the necessity of swinging to the tide.

Mr. MURRAY said, in order that a correct appreciation might be formed of the effect of the works executed, and to supply the want of information as to the soundings in the Tees, between the bar and Stockton, the limit of the navigation, and as to the tides

flowing up that river, he had drawn up, in a tabular form, a comparative view of the states of the river in the year 1824, and in the year 1839. The Table was compiled from a series of soundings, taken by Mr. Johnson, the superintendent of the river, in the years 1838-39, from Stockton downwards to Cargo Fleet, with transverse soundings at various points; and from the soundings upon Mr. Brooks' chart, taken in the year 1824, before any works were constructed. The distances between Stockton and Cargo Fleet were divided into certain portions, partly straight and partly circuitous :—

Comparative State in 1824 and 1839.

	Distance in Miles.	Depths at High Water ordinary Spring Tides.				Increase of Depth.	
		1824.		1839.		1824.	1839.
		Minimum or available.	Average.	Minimum or available.	Average.	Minimum or available.	Average.
		Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.
From Stockton Bridge to Blue House Point.	1 3/20	10 0	14 8	15 0	17 6	5 0	2 10
From Blue House Point to the lower end of the Cut of 1831	3/4	..	..	17 6	21 6	5 6	5 2
Old Course by Portrack.	..	12 0	16 4	..	..		
From the Cut of 1831 to Newport	1/2	13 0	14 9	17 0	19 6	4 0	4 9
Along Bellingham Reach	1 1/5	14 0	15 8	16 0	16 10	2 0	1 2
Through Bamblet's Bight	3/5	14 0	17 10	16 9	22 6	2 9	4 8
From Bamblet's Bight to Port Clarence	1	15 0	16 4	18 3	20 1	3 3	3 9
From Port Clarence to Cargo Fleet	3/4	18 0	20 2	21 1	25 3	3 1	5 1
	6 1/8	miles.			mean =	3 8	3 11

There could be no doubt, therefore, that if improvements had been effected in Bellingham Reach, in the same manner as had been done elsewhere, there would have been a greater depth in that portion of the river. It was between Bellingham Reach and Cargo Fleet, that the coal trade was carried on, at Middlesbro' on the right bank, and at Port Clarence on the left. In the year 1836, Jetty A was the head of this reach, where the breadth to the opposite sand was, at low water, 620 feet, with a sectional area of 1,821 square feet. The breadths and sectional areas

at different points were shown in the following table, in which was also given the state of the river in 1839, after the completion of the works in Bamblet's Bight, and the prolongation of the jetties in Cargo Fleet Reach :—

CARGO FLEET REACH.

	Breadths at Low Water.	Sectional Areas.	
		1836.	1839.
	Feet.	Sq. Feet.	Sq. Feet.
From Jetty A to sand opposite	620	1,821	..
„ „ „ to Jetty A'	401	..	3,983
„ „ No. 5 to No. 8 Coal Staith	594	2,835	..
	496	..	3,976
„ „ e, to No. 4 Coal Staith	516	1,202	..
	522	..	3,860
„ „ E to Ballast Staith	600	..	4,069
„ New Jetty to Pottery Staith	500	2,029	..
„ „ „ to New Jetty below Pottery Staith	569	..	4,980
„ Port Clarence Staith to No. 2 Jetty opposite	500	..	5,000

He had also examined some valuable documents in the possession of the Tees Navigation Commissioners, which had been courteously lent for the purposes of the discussion, with tidal observations on a large scale, made in 1824 and continued down to 1853. He had abstracted the longitudinal soundings in the same divisions of the river as marked in the preceding table, and had found that the available, or minimum depths, as well as those on the average, had slightly increased, in the upper part of the river, but had slightly diminished, in the lower reach between Port Clarence and Cargo Fleet. These documents proved, that an evident improvement had been effected by means of the works carried on between 1824 and 1839; and that the river had maintained itself between 1839 and 1853, the date of Captain Calver's survey. In further proof of the beneficial effects produced, it might be stated, from a report furnished to the Admiralty by Mr. Bald, that in the year 1808, before any works were executed, a vessel of 105 tons register, and drawing 11 feet, had always to be lightened before it could be brought up to Stockton: then the greatest draft with which a vessel could come up was, on good spring-tides, 9 feet of water, and in ordinary spring-tides 8½ feet; at the present time, the river was navigable as far as Stockton, for ships of 350 tons, with from 15 feet to 16 feet draft of water.

The cost of the works of the two cuts, and the jetties for contracting the channel, without dredging, or with only partial dredging, had been £110,000, or in round numbers, taking the distance at 6⅛ miles to Cargo Fleet, £18,000 per mile.

In the Clyde, transverse stone dykes were run out at right angles to the shores, and some time afterwards the late Mr. Rennie recommended that the dykes should be connected by longitudinal walls. The river, for some miles below Glasgow was now, in consequence, much contracted; and, sooner or later, it would be necessary to set back one of the walls, to increase the width of the river. By continued dredging, a greater depth of water would be obtained, but the consequence would be, that the longitudinal stone dykes at present existing would be frequently undermined. Under the jetty system, dredging, for the purpose of removing shoals, would not have produced that mischief.

In the Clyde, a hundred years ago, on the Broomielaw Sand, a little way below Glasgow harbour, there were only from 15 inches to 18 inches of water, and a flow of 1 foot 9 inches, giving a depth, at high-water spring tides, of 3 feet 3 inches; at Newshot Island, 7 miles below Glasgow, there was a depth at low water of 2 feet, with a rise of 6 feet, making a depth, at high-water spring tides, of 8 feet; at Dumbuck Ford, 12 miles below Glasgow, there was a depth at low water of 2 feet, with a rise of 9 feet, or 10 feet, making the depth at high-water spring tides 11 feet, or 12 feet. It appeared from the Admiralty chart of 1846 that the available, or minimum depth was:—

——	At Low Water Springs.	Rise of Tide.	At High Water Springs.
	Ft. In.	Ft. In.	Ft. In.
In the reach between Dumbarton and Bowling .	7 0	9 0	16 0
Between Bowling and Newshot	7 6	9 0	16 6
„ Newshot and River Cart	9 0	9 0	18 0
„ River Cart and Kelvin	7 0	9 0	16 0
„ Kelvin and the lower part of the harbour	8 0	9 0	17 0

It was intended to make:—

The width in Glasgow harbour	420 feet	With a low-water depth throughout of 10 feet.
At the Kelvin	360 „	
Gradually expanding at Dumbarton, to	1,053 „	

The expenditure on the works in the Clyde, to the year 1846, appeared to have been about £1,254,000. Taking the harbour

of Glasgow as being one mile in length, and 400 feet in width, with from 8 feet to 10 feet depth of water at low tide with quays on both sides, the expense would be about £254,000. If then, this sum were deducted from the former there would remain £1,000,000 for the deepening of the river and the dykes, and for the jetties on each side, in a distance of 13½ miles, making £74,000 a mile. Looking, therefore, at the excessive difference of cost per mile between the works in the Clyde and those in the Tees, he could only account for it by the dredging that had been carried out in the former river. An endeavour was now being made to obtain 10 feet of water at low water throughout, from Dumbarton to Glasgow. That depth was beyond the scouring power of the currents of water passing down the river, even in floods. Therefore a large sum would have to be annually expended in dredging, to maintain such a great depth. The expenditure given, extended over the period from 1758, to the present time, and included maintenance. The £110,000 expended in the Tees, was from 1808 to 1846, and was exclusive of dividends, interest on loans, salaries, law charges, office rent, and incidental expenses, which brought the total cost to about £21,000 per mile, as against £74,000 in the case of the Clyde.

Mr. LECKY said, he would state the result of the dredging in Cork River. In 1825, when the Cork Harbour Commissioners began operations, it was necessary that vessels of 200 tons should be lightened of a portion of their cargo at Passage, seven miles below the city, before coming up the river to discharge the remainder. At the present time, vessels of from 600 tons to 800 tons could come up to the quay with ease. In 1851 he was employed by the Commissioners to build a larger dredge-boat, capable of lifting 400 tons per hour. Since that period, dredging had been carried on to such an extent, that the quays were made accessible to vessels of even 1,000 tons. There was very little training of the banks, except at the city itself. The cost of dredging was about 4*d.* per ton, and the engines were of 50 H. P. About the year 1843 the Commissioners took in about 300 acres of the upper portion of the river below the city, but the silting was so small, that the deposit amounted to only about 3 inches each year.

Sir JOHN RENNIE, Past-President, said, he felt much obliged to the Author for having brought before them the interesting subject of this class of harbours, which might be termed fluvial estuary harbours. The discussion, as yet, had turned more on the question of constructing jetties than on the real principle of managing and improving harbours of this kind. It was to be regretted that there were not both cross sections and longitudinal sections, showing the state of the river before the operations were commenced, as also the

effect of those operations after having been carried so far. This alone would have afforded the means of forming an opinion as to the judgment with which those works were designed, and the effect that had been produced by them. According to one opinion, it was useless to attempt to improve this harbour. But the Clyde, the Tyne, the Welland, the Witham, the Nene, and many other river harbours had been beneficially affected by the operations of the Engineer, and therefore, it could not be said that engineering operations, in such cases, were exercised in vain.

It therefore became an important question to consider, what was the best mode of treating harbours of this class, namely, fluvial and estuary harbours? These, in many cases, if left in their natural state, were unfit for drainage, or navigation, according to the improved requirements of modern times.

The plans generally adopted by the best authorities, to obtain these desirable results, consisted in a system of jetties or works of a similar character, placed transversely, or longitudinally with the line of the currents. The proper application of these systems depended to a considerable extent upon local circumstances; sometimes the transverse, sometimes the longitudinal, sometimes the two systems combined, would produce the most favourable result. The great object was in all cases to obtain the largest channel as regarded width and depth, with a certain degree of velocity of current, so that the quantity of water passing in and out would maintain the channel in a uniform state at its maximum; and the jetties, or other works, should be raised no higher than was necessary to effect this, in order that as much tidal and fresh water should be admitted and discharged as possible. Another important question was the bar of the river. The bar itself was a material point in the case; for where the river passed the outer land points and entered the sea, the antagonistic forces of the winds and waves without were so great, compared with the quantity of water discharged, that it required certain guides to enable the latter to act effectually upon the bar. Hence there could be no doubt that guide-piers were necessary; and the plan of these guide piers and the width of the entrance were essential elements in solving this question. The entrance, also, must be made in harmony with the tides, the currents, and the winds, which produced these extraordinary external forces. Supposing these operations to be properly designed in the case of the Tees, there could be no doubt, that the waters from within, combined with those coming into the harbour, would assist in reducing the bar, and driving it into deeper water, so that there would be a greater depth of water over the bar than could be otherwise obtained. He was not sufficiently acquainted with the Tees to go into details. That this river had to a certain extent

been improved might be true, but he believed, at the higher reach, that was scarcely the fact. He thought, considering the large expenditure that had been incurred, that was a great defect, and he believed that large operations remained to be carried out at the mouth of the Tees, to produce greater effects than had yet been brought about; but whatever was done, care should be taken that the greatest quantity of tidal water should be admitted, and that both the fresh and the tidal waters should be made to act with the greatest possible beneficial effect upon the channel and the bar.

He considered that jetties, if properly constructed and applied, would be beneficial, even where the stream became very wide. He thought also, that in designing the entrance, it was important that the guide piers should be constructed in such a manner, that the in-coming and out-going waves might expand themselves, so as not to produce an injurious effect upon ships coming into, and departing from, the river.

Mr. BEARDMORE remarked, that jetties, though their beneficial effect was limited in area, and though liable to other objections, were the cheapest means of guiding currents, and of thereby producing deeper water. In the Clyde, during the latter half of the past century and in the first quarter of the present, before steam-dredging was invented, great improvements had been made by means of them; below Glasgow, where formerly there had been only 2 feet of water, the effect of the jetties, roughly constructed as these were, was to give a depth of 8 feet or 10 feet. He thought them still valuable in the preliminary treatment of rivers, and in a new country, such as Australia, or New Zealand, he would probably begin by constructing them of the readiest materials, such as wattling; but afterwards when capital became more abundant, and ironworks were as numerous as at Middlesbro', he would, if available, use slag, and to the amount of 20,000 tons per month.

With reference to the Tees, the true mouth of that river was at Middlesbro'; the rest of the estuary was an open expanse of sands, with low-water channels, forming only a small stream, when compared with the area of the estuary at high water. Above Middlesbro' the river was distinct from the estuary itself; the latter was, originally, a deep bay in the coast, which had become, by the gradual and long-continued descent of sand from the Yorkshire hills, a flat expanse, through which the river found its way. The attempt was now being made, to obtain a fixed channel, and the training-walls, under process of construction, would be of great advantage; but the area to be dealt with was so large, that a long period of time must elapse before any considerable effect would be produced; in fact, the full benefit could not be realized till dredging

was actively commenced. It had been remarked, that the walls were too far apart; but it was stated in explanation, that the worst shoals were to be removed by dredging, and that, when an unobstructed sweep had been made in the river, the scour of the tide would materially aid in the work; and that had a different course been chosen, the walls would have interfered with the anchorage-grounds, both of vessels going up to Middlesbro' and of the proposed harbour of refuge.

He would suggest, that great allowances ought to be made, for the peculiarities of the lines of the work. At the southern bend of the river below Middlesbro', there were 50 feet of loose, soft silt. The longest pile would scarcely take hold of the ground, and the operation must have been governed by the necessity of following that line, where the labour would be least arduous. He regarded the original and subsequent improvements in the Tees, taking them upon the whole, as an admirable work, especially when he considered, that those operations then represented a much larger pecuniary value than the same amount of labour at the present day.

Mr. J. Scott Russell said, he had been for many years familiar with one of the best treated rivers in this country and one of the worst. One of the best treated rivers was certainly the Clyde; and it was remarkable and instructive, while discussing whether dredging was better than parallel groynes, and parallel groynes better than rectangular jetties, to find that the Clyde had been treated by all these methods together. That rather led to the conclusion, that rectangular groynes might be good for one thing, parallel groynes for another, and dredging for something else.

Now, he would give another case, of a river which had been improved "out of itself," for it was no longer a river, but a canal and estuary mixed together, with the channel and sandbanks in inextricable confusion. He spoke of what was once the noble river of the Dee up to Chester. Ships lay under the great wall of Chester; fleets sailed from 12 miles below Chester on the opposite side: and now nothing but one or two small cheese-boats ever got near to Chester; and he did not think any large merchant-vessel ever got up above Flint. The improvement of the Dee consisted in doing what some would judge, from other practice, to be the best possible thing. The channel was made perfectly straight, all the bends being taken out: then the river was groyned longitudinally, to begin with; then after a sufficient number of years, and when the channel had been sufficiently injured, it was groyned transversely, and that finished it.

It had been his duty to make a careful survey of the river Dee on two separate occasions: it had often been said, that if Engineers

would relate the mistakes they had made, they would give more valuable contributions to science than by telling their successes; and he thought he had derived more information from studying the errors in the treatment of the Dee than from studying any other river.

He would next endeavour to get out of the treatment of the Clyde, compared with that of the Dee, what it was that constituted good treatment of a river approaching to the nature of those two, and therefore approximately applicable to the Tees. For, by the various experiments made on it, it had come to be in the condition of the Clyde at one period of its history, and of the Dee at another. It seemed to him that when one of those rivers required improvement, it might be considered to be in some of the following circumstances: either it had too little water uniformly over the whole of the upper reach to be of any use for navigation; or the water was so irregular, the current so uncertain, and the depth so variable, that though there was plenty of water where it was not wanted, there was not sufficient water where it was wanted.

The first question that occurred to most Engineers, looking at a river, was this, "Shall I leave the river with its natural bends as they are, or shall I take out the bends and make them straight?" and he thought, that was one of the most critical periods in the history of a river. To attempt to make part of a curved river straight, was a dangerous undertaking. From the nature of any navigable river, he should say, if there was depth of water enough, and if there were gentle curves, and if that depth of water, and the velocity of the stream, and the slopes of the bottom and of the top were all tolerably uniform, he would on no account interfere with the natural bends of the river; but under those circumstances he would keep every bend just as it was, and proceed by another process. He would state why he thought the natural bends of such a river ought not to be meddled with. In the first place, if a river were tolerably straight and funnel-shaped, and if it had a uniform slope of bottom, and a uniform increasing depth of channel, and funnel-shaped banks, nobody would dream of altering it. However, that was not the state in which a river was generally found. A river had, for some reason or other, an oscillating motion; and there was a similar process going on in it to that which went on in a pendulous body. A pendulum set in motion, continued to oscillate isochronously, without the expenditure of any new force: and in like manner, if once a curve or bend was established in a river with considerable current, the mere fact of the commencement of curvature would give it a tendency to continue that curvature, and the river would go on oscillating regularly to the sea, in curves

of opposite curvature. Nay, more, having one of these bends, if the channel were of uniform materials, it was possible to say what the curvature of the river would be, as it went towards the sea. Let it be supposed that such a river as this was interfered with: that the Engineer was asked to improve this channel formed of oscillating curves, and that the first thing he did, was to put a straight cut from one curved part of the channel to another. He need hardly say, such an interference with the river would be a grave mistake, because it would interrupt the continuity of a system of oscillations.

Now just such a river the Dee was, once upon a time; a gently undulating channel, going along by Chester down into the sea, gradually growing deeper and wider. All around this river was a large tidal estuary, filled at half-tide. There was this winding half-tide channel; but at high water the whole of this estuary was filled, and as soon as the water got down to half-tide level, the whole of it rushed into the nearest point of the channel, formed a scouring stream, maintained itself in it to a late period of the ebb, and thus kept up a navigable natural channel. The water once put into this oscillatory condition, maintained itself by impinging against the side, scouring to a great depth at one side; then going to the other side, and scouring that, and so perpetuating a series of oscillations natural to this river. But the Engineers of the day said they would improve this river by straightening it. The bends were taken out of the upper part, and the river was conducted by an almost straight channel, ending in one of the bends, or curved reaches. The length of that cut was, speaking from recollection, about 7 miles. This having been done, the idea no doubt was, that the river below the straight cut would still keep up its oscillations; but it had nothing to make it begin to oscillate; it had only a longitudinal motion. The water came straight down as long as it could; but that was only until it had spent its strength against the opposing bank. Then it wore away the curved channel, until it entirely altered its form and diverted the current from its old bed. Meantime the old channel continued to exercise some influence over the waters; and in the contest between the two, confusion ensued, and large and irregular banks, and irregular, variable channels were the result. In this condition of affairs the flood-tide rushed in and added to the confusion of the multitudinous diverting channels made by the altered out-flow. Thus this noble navigable winding channel was destroyed by straightening it. Therefore, if a river had a bottom of a tolerably even slope, and a stream of tolerably uniform depth throughout its bending course, it was better to preserve and improve its gentle winding channel than to straighten that river.

Next,—what would have been the proper treatment of this river?

He would say, certainly the treatment the Clyde had received. He remembered the Clyde perfectly well, when it was a marvel to see a two-masted vessel of 120 tons reach the Broomielaw. In his time, such a vessel might reach that basin in the high tides of March, and leave in the high tides of August. It was improved out of this condition, in the following way:—In the first instance, by merely putting out groynes, wherever the river was deviating too far from its course, or where it had a double course with an island in it, by closing up one. The next application of the groynes, was to restrain the river where its course became so devious as to throw up shoals. Gradually it was thus reduced into a regular winding channel, and, after some time, parallel groynes were put in to define the river where it had a tendency to encroach upon the bank, either on the flowing or the ebbing tide, and so to give a more uniform velocity to the stream. This having been done, a time at last came when the slope of the river became perfectly uniform; when the natural stream had done all its excavation, and when no more excavation was taking place. Now it was quite plain, that when every obstruction and irregularity had been removed from the river, and it had become uniform, there was little more to be done by the natural aid of the stream, and here ended the first period of improvement, and the first system of operations by the natural forces of the stream.

When the engineers of the Clyde had reached that point, and had reduced the bed of the river to a uniform slope at the bottom, to a channel of nearly uniform width, and a depth gradually increasing downwards, he did not think they could do more. When by any means of scouring, the bottom of such a river, which was 8 feet higher at Glasgow than at Dumbarton, could be deepened on a uniform slope, was without impediment, and had a uniform stream flowing over it; what reason would there be to suppose, that any arrangement that could be made would deepen that channel? Certainly, if the channel was sufficient to hold the water of the river at low water, and no more, nothing that could be done would increase the depth of that channel, or make the scour greater.

Now at this period came in the use of systematic dredging: from this moment it was only possible gradually to deepen the river by dredging upwards, and so reducing this 8 feet of slope of the bottom of the river. That was what the Engineers had done at Glasgow. They had dredged backwards and upwards; but at every step they dredged, what was the consequence? As they had gone on dredging, they had diminished the speed of the river, and its scouring power, so that now at low water there was hardly any sensible current in the river at all. Therefore it was quite plain, if they had depended on scour for either gaining

or maintaining this new depth, they would never have got the scour to do it; and he ventured to say, that without dredging, the last 8 feet in the Clyde could not be maintained and never could have been obtained.

There was one further element in the improvement of a river, and the natural consequence of parallel groynes. It was an important, but only a limited one. By means of it, it was possible greatly to accelerate the motion of the tidal-wave up the river, and so lengthen the period and increase the amount of deep water in the Channel.

Something had been said about keeping a large surface of the river open for the tidal water, but, he thought, it was in many cases very doubtful, how large an area of surface should be kept open for tidal water. It was often better to have a deeper channel and a narrower reservoir of tidal water, than a wider and shallower one; because the deeper channel would receive water earlier, and give it out later than the shallower; and, moreover, it would contain a larger volume of water for scour in the lower tides than the shallow reservoirs. He therefore should often recommend that the mere superficial area for receiving tidal waters should be diminished, where compensated by a smaller area of deeper water, which would be more effectual for all purposes of scour. By this narrowing and deepening of the water-way, high water was enabled to travel a greater horizontal distance up the river: high water was carried up the river earlier, therefore deep water was maintained in the river longer. Thus the diminution of superficial area of waterway of a river might be so counterbalanced by the additional advantage of the increased velocity of the tidal wave, that in many cases it might be prudent to resort to that operation. It must depend on what part of the river was intended to be benefited, whether this course were wise or unwise. It would be unwise if it were sought to benefit the part of the river below this point to subtract this additional water area; but if it was desired to benefit the river above the place operated on, then a better thing could not be done. He was thus explaining how to benefit one particular portion of a river, and guarding against the risk of doing injury to some other portion.

There was great difficulty in defining what was a principle in engineering. Sometimes it was said, that no general rules could be laid down, but that the Engineer must act according to circumstances. He thought that was insufficient. It was necessary to act according to circumstances, but it was equally necessary to have some principle as a guide, and to apply that to the circumstances. He had endeavoured to discriminate, as nearly as he could, what were the circumstances in which one, or the other, of these methods was useful, and also where the alteration of the

tidal channel would do good, and where it would do harm. It would not, however, do to assume a principle as applicable to all sorts of cases; and perhaps the wisest man was he, who, with all his principles in his head, never applied them dogmatically, but first of all mastered all the circumstances of the case, and afterwards selected, with caution, only those methods of operation and principles of action which most precisely fitted all the conditions of each case.

Mr. W. PARKES said, in reference to the remarks based on the assertion that the River Clyde was the best managed river in the kingdom, whilst the River Dee was the worst,—with the first part of the antithesis he did not find fault, but he could not concur with the second, as he thought that conclusion had been arrived at from all the circumstances not being taken into account. It was quite true that the Clyde and the Dee presented a great contrast; but in order to present a fair contrast it was requisite to know somewhat definitely, to what extent the cases were similar. The points of resemblance between the Clyde and the Dee were few. Both were the approaches to inland ports at nearly the same distance from the sea; both were rivers of about the same volume of discharge; both were treated, at certain periods of their history, by means of transverse groynes; and another point of resemblance was, that during critical periods both were under the direction of the same Engineer. If it were true that the one river was the best managed, and the other the worst managed, it would appear that the first President of the Institution, Mr. Telford, was in the habit of going to Glasgow, inspecting the Clyde, and there recommending measures based on the most approved principles of engineering; that then, on his way back to London, he would go to Chester, inspect the River Dee, and there recommend measures based on most mistaken principles. If that were true, such an anomaly was worthy of record; but he thought it was not altogether true. On the contrary, it could be shown that the Dee presented instances of skilful engineering; and if the results were not equal to those shown in the Clyde, it was because the results desired to be obtained were so very different in the two cases.

The points of difference between the Clyde and the Dee were much more striking than those of resemblance. The estuaries were very different in their form, in the nature of their beds, in the direction of their exposure, and also in the height of the tidal wave which filled them twice in every twenty-four hours. That which filled the Dee was about three times the height of that which filled the Clyde; consequently, the tidal currents were more rapid in the Dee than in the Clyde.

Then in a commercial point of view there was a great contrast.

Glasgow was the centre of an important commercial district, both mineral and manufacturing. Chester was an outlet for a not particularly important agricultural district, and it was very near the important port of Liverpool, through which the great bulk of the trade of the neighbourhood necessarily passed. With regard to the comparison of Chester and Glasgow from this point of view, he would quote the concluding words of Mr. Telford's "Report to the River Dee Company," dated July 23rd, 1828:—

"During the last two months I have examined and reported upon four navigable rivers, viz., the Dee, at Aberdeen; the Tay, at Dundee; the Forth, between Leith and the opposite coast of Fife, and the River Clyde, below Glasgow.

"In every river there are local peculiarities, but the last mentioned, viz., the Clyde and the River Dee, at Chester, bear the greatest resemblance in regard to their navigable length, the dimensions and shape of their estuaries, and the means which have been employed to acquire and maintain a proper depth of water in their upper portions.

"The Clyde has not been rendered so perfect as the Dee, but similar means are still employed to render it so; and there has now been obtained from 11 feet to 12 feet at good spring tides; but with a navigation which is evidently inferior to that of the Dee, there is now produced a revenue of £18,000 a year."

Now, at that time the revenue derivable from the trade of the Dee, notwithstanding that its navigation was better than that of the Clyde, was so small that it was not even collected, and if it had been collected, it would not have exceeded £300 a year; so that, in that respect, there was a great point of difference between the Clyde and the Dee. Connected with this great difference in the revenues of the two rivers, were the circumstances under which the works of improvement were conducted. He believed considerably more than £1,000,000 had been spent on the Clyde, the whole of which money was raised, from time to time, on the security of the revenue derived from the trade of the river. Rather more than £100,000 only had been spent on the Dee; and he believed that at no time, during which Chester had been a port, could £5,000 have been raised on the security of the tolls. The money that was obtained was raised in a totally different way.

So much, then, for the contrast between the Clyde and the Dee; but another contrast had been presented, viz., Chester as it was, and Chester as it is. As regarded the ancient prosperity of Chester, he would not dispute that there might have been a time when Chester was prosperous; but that time was lost in the mazes of antiquity: it certainly had not been within the last four hundred years, and the decadence of the port had nothing to do with the works which had been so strongly condemned.

The following were the results of some inquiries into this matter, which he had made eighteen years ago, by direction of the late

Mr. Walker. He thought if he went back three hundred years, that time would be quite remote enough; it would then be one hundred and fifty years previous to the interference with the river which had been condemned. In Ormerod's "History of Chester," the state of the river in the latter part of the sixteenth century was thus described:—

"The haven which in time past received ships of great burthen up to the city skirts (as hath been vouched) scarce now has sea-room for small barques, which only at high water do bring their unlading of great vessels from the quays and stations which can receive them five, six, or ten miles off."

He now passed over a period of one hundred years, when there appeared a curious little work, by one Andrew Yarranton, entitled "England's Improvement by Sea and Land," in which it was said:—

"In the month of July, 1674, I was prevailed with by a person of honour to survey the River Dee, running by the City of Chester into the Irish Sea, and finding the river choked with the sands, so that a vessel of twenty tons could not come up to that noble city, and the ships forced to lie at Neston (eleven miles below Chester), in a very bad harbour, whereby the ships receive much damage, and trade made so uncertain and chargeable that the trade of Chester is much decayed and gone to Liverpool, and that old great city in danger of being ruined," &c.

That was in 1674. In 1684, Captain Grenville Collins, hydrographer to the king, made a survey. He had not seen the original of this, and the copies he had seen did not give the depth of water in the upper part of the estuary. In the year 1700, an Act of Parliament was obtained, by the mayor and citizens of Chester, probably as the result of what had previously been written by Yarranton, and of Capt. Collins's survey. The preamble stated:—

"That the river was theretofore (that is previous to 1700) navigable for ships and vessels of a considerable burthen from the sea up to the City of Chester, but that the navigation to the city was at the time (1700) almost lost and destroyed."

The desire, at that time, was to make the river navigable for ships of 100 tons, and to do that, would have required a depth of 10 feet or 11 feet—a fact which showed that that depth did not then exist. That Act was to be in force for twenty-one years, during which time the authorities had power to levy tolls on shipping for the maintenance of the navigation. At the end of the twenty-one years those powers lapsed, so far as was known, without any permanent benefit having been effected, and for ten years subsequently nothing seemed to have been done. Afterwards the idea appeared to have been entertained, that the trade of Chester would never pay for the necessary outlay on the river, and therefore

some other means must be adopted to obtain the required funds. Accordingly negotiations took place between Nathaniel Kinderley and the citizens, of the exact nature of which there was not any record, so far as Mr. Parkes was aware, but the effect was, that in consideration of a depth of 16 feet at high water being provided up to Chester—that was, about 6 feet more than the citizens had previously attempted and failed to obtain—Kinderley should be allowed to reclaim any land in the estuary that he could. To do this he cut a new channel through the marsh for the length of about 10 miles, and made a bank on the estuary side. Through this channel the waters of the river were conveyed, and the old estuary was allowed to silt up. Thus, in course of years, portions of land were reclaimed. This cut was commenced in 1732, and the plan was opposed by parties in Chester, on the ground that the reclamation of the land would reduce the tidal capacity of the estuary. The opposing parties referred to a plan which seemed to have been an original survey made by John Mackay, mathematician. In a note on this plan it was stated:—

"Between Chester, Flint, and Parkgate 7,000 or 8,000 acres are proposed to be gained from the sea, by which means no less than two hundred millions of tons of tyde will be prevented from flowing there (twice in 24 hours), which on the reflux acquireth the greater velocity to scour and keep open the Lake and Barr: whether these ill consequences (which must certainly attend the present undertaking) are not more likely to destroy the present navigation in Hyle Lake and the River Dee, rather than recover and preserve a better, is humbly submitted to the Right Honourable the House of Lords."

It should be observed that this plan came from Kinderley's opponents; and there were no doubt Engineers of the present day who would endorse the opinion given, that the effect of reclaiming this land would be to injure some part of the lower estuary. It did not appear, however, that any great injury was inflicted: the deep water shifted from the north to the south side of the estuary, but the depth in the new channel was not materially different from what it was in the old one. Mackay's plan, however, was evidence of the state of the navigation at Chester in 1732. It was natural to suppose, that it would show the best of the navigation which the opponents thought was about to be injured, and what it did show was a depth of 9 feet at high water at Chester, and 10 feet at a point a mile and a half lower down. In spite of this opposition Kinderley proceeded with the work, in the hope of obtaining a permanent depth of 16 feet at high tide at Chester. A few years afterwards he sold his interest to a joint-stock company, known then, and now, as the River Dee Company, and they found they could not manage to maintain the depth of 16 feet; but they undertook, in consideration of the tolls being reduced, to maintain a

depth of 15 feet, by a mark on the river bank. It was alleged, on the part of the River Dee Company, that that depth had been maintained up to the present time, and having looked into the matter, Mr. Parkes was himself satisfied that it was so; and although a foot or two of that depth was matter of dispute, the fact that from 13 feet to 15 feet had been maintained for one hundred and thirty years was not disputed, and this depth of 13 feet to 15 feet was as against 9 feet when Kinderley undertook his works, and for at least one hundred and fifty years previously.

As the discussion, however, was on the River Tees, and not on the Dee, he would not say more, except to point out what he considered was the real lesson to be learnt, not failure from bad engineering, but an instance in which a certain depth of water, which had been obtained one hundred and thirty years ago, had, in spite of natural deteriorating influences, been virtually maintained to the present time. Instead of the money being gradually raised, and the improvements carried out step by step, as the increasing trade demanded it, as in the Clyde, the whole of the money was, in the case of the Dee, raised from a fund independent of the trade, and a large measure of improvement carried out at once. A contract was entered into, that a certain depth should be made and maintained, and the skill of the Engineer was not exerted to make further and subsequent improvements, but merely to carry out the agreement that had been entered into for the maintenance of that contract depth. This in itself was a difficult work, considering the natural deteriorating influences going on, but it had hitherto been successfully accomplished. The Engineers engaged on this work were, first, Mr. Goulburn, then Mr. Jessop, and next Mr. Telford, and since the death of the latter, Mr. Provis had been consulted up to the present time. Mr. Parkes submitted that these eminent Engineers had in their turn evinced great skill in maintaining the contract depth at a comparatively small outlay, and which outlay was in no way contributed to by the trade. Under the circumstances he did not think the character of the worst-managed river in England was fairly to be given to the Dee.

Mr. G. W. Hemans said, it had been remarked that the works by which so near an approach to perfection had been attained in the Clyde were excessively costly; and it was clear, that if the good results stated to have been obtained in the Tees had, with some similar characteristics, been effected at a cost of only £18,000 a mile, and that if the outlay on the Clyde had been £74,000 per mile, the disparity would be remarkable; but he had inspected the works on that river, and he felt sure, that a larger proportion of the whole outlay, was to be set down to the cost of the works in

the harbour of Glasgow than had been supposed, and upon inquiry he had found, that the outlay upon this portion had been £580,000. Deducting, therefore, £580,000 from the total outlay in connection with the Clyde, there remained £30,000 per mile, for the navigation works, instead of £74,000. The Clyde had been dealt with by many Engineers, and each had introduced a new mode of treatment, but the whole result must be regarded as very satisfactory.

Much interest had been taken in the question of the comparative merits of cross groynes, or jetties, and longitudinal walls, in correcting the wanderings of a river; and opinions were generally in favour of the latter; but he thought a good deal might be said in favour of cross groynes. No doubt, this would be a costly method of straightening the course of a stream through the sands of a trumpet-mouthed estuary, but in a long and narrow channel, he believed cross groynes would be cheaper in shallow water than longitudinal walls, and there was this advantage, that the earthy matter brought up by the tides, being deposited in the bays formed between the groynes, caused them to silt up, eventually becoming valuable land, and made the operation of connecting the ends of the cross groynes by longitudinal banks, much easier. That was exactly the system carried out in the Clyde, by means of long, rough rubble walls, restricted in the first instance below low water, and afterwards brought up above the current. In the Liffey, both systems were now in operation, and at the North Bull, there was a cross groyne of great length, which was of extreme value in producing a scour on the bar. He should not recommend the enclosure of the Tees within parallel walls. Each case depended upon its separate requirements. Where the estuary was long and narrow, it might be prudent to commence with cross groynes; where it was wide and trumpet-mouthed, longitudinal walls might often be preferable.

Mr. W. A. Brooks observed that, in 1831 a survey was made which showed the state of the Tees when it was affected by the rain water, but not the summer state of it; at the time that section was made, the western dam of the cut of 1810 had not been removed. The ancient level of high water at Stockton was below the level of the sea, and the level, as taken by Captain Calver, showed a depression of 3 inches below the high water of the sea. Captain Calver's survey also recorded a depth of 8 feet at low water on the bar, while previous observations showed a depth of only 6 feet; that improvement was mainly due to an improvement which had taken place at the 'outer stones.' According to Captain Hewett's survey, there was then only 3 feet depth at low water on the 'outer stones' at spring tides; according to Captain Calver, a depth of 11 feet was shown, so that the ebbing water was

now enabled to discharge itself more readily, and there must be also less obstruction to the flow of the flood tide. Another observation, which should be recorded, was, that the datum of Mr. Price's survey was 2 feet below the coping of the quay on the west side of Cargo Fleet Mill, and the same datum level was 3 feet $3\frac{6}{10}$ths inches below the top of the string course of Stockton bridge, on the north side of the Yorkshire shore.

In estimating the cost of the improvements on the Tees, the length of the works had been calculated at only $6\frac{1}{8}$th miles; but the real length, taking the old circuitous route between Stockton and Cargo Fleet, was 10 miles; this showed that the expenditure per mile was not more than £11,000.

It had been said, that no parallel walls had been carried out in the Tees, and to that circumstance had been attributed, in a great degree, the want of the full success which had attended the operations in the Clyde. The fact was, in the improvement of such rivers the construction of the groynes was but the first step. The jetties themselves were nothing more than a preparation for the future amended course of the river; and, if shorter groynes had been made, between the present ones, and terminating at the new foreshore, or river line, the formation of land would have been accelerated, and thus the effect of longitudinal walls would have been produced. It had been suggested, that it was better to make the walls to the height of half tide only, in order to allow the tide to pass over, and spread between them and the shore, and, that had that method been adopted, the tidal space between the old channel and the new, or contracted channel, would have been preserved; but, the ultimate formation of land being merely a question of time, he believed, that if the course of the current of the ebb tide were once fixed, land must be eventually formed between the training walls and the old bank of the river. As a general rule, it was better at once to raise the transverse jetties to the level of high water of spring tides. The original transverse jetties planned by Mr. Rennie for the Tyne came up to high-water mark.

With respect to the supposed advantages of steam-dredging, the natural power of the stream could be so directed as to produce the same results, at a considerably less expense. Training walls, he considered, should not be erected in such positions as to be exposed to the action of currents. He had carried out similar works on the Tyne; the first operation was to throw out a jetty on the western side, to take off the effects of the ebb tide: subsequently he carried up connecting walls to the level of half tide; the ground between jetty and jetty rapidly shoaled up, and the work did not cost one-fifth of what it would otherwise have done.

A case had been supposed of a river which might have a tortuous course and yet be perfect, but he thought it was impossible for the channel to be tortuous and yet have the qualities which had been attributed to it; with every change of course there must be a shoal.

Mr. T. Marr Johnson observed, that the maximum of improvement in a river was effected when the greatest amount of vertical range was obtained for the tide for the greatest distance inland; that the limit to the improvement of a tidal river was determined (ceteris paribus) by the extent of tide at the outfall; and that to obtain the full advantage of this range, it was necessary that all the conditions of depth, width, and inclination of the bed should be properly proportioned. It appeared that a serpentine course was not calculated to promote this object; for, in proportion as the distance from point to point was increased by the bend, so was the tidal range diminished; and, again, the same flatness of inclination could not be obtained, because every bend was an obstruction, and every obstruction increased the inclination of the water surface, and thus, the actual range of tides was diminished in even a greater ratio than the increase of length. The ebb and the flood could seldom take the same course, in a serpentine channel; hence it was impossible that the bed of such a river could be deep and uniform. Therefore in designing a new channel for a winding river, the existing sectional area at the outfall should be preserved, and all the sections of the new channel should be so proportioned, that the same sectional area should be preserved in the new as in the old channel at the same distance from the outfall, such distance being in each case measured along the line of channel; by this means there would be no reduction in the volume of tidal water, but the contrary.

It was certainly desirable, that the design of the whole river should be completed before any part of the work was commenced, but the adaptation of a partial improvement to a complete measure was not so difficult as it might at first appear; for example, if only one bend could be taken away, the final proportion of the cut might be observed, and the current might be prevented from wandering, and being deflected from side to side in a channel, at first too large for it, by making it in a very gentle curve. By closing the upper end only of the abandoned channel, the tide would still flow into it, and thus keep up for a considerable period of time the same quantity of ebb water for scouring the outfall; the bend above Middlesbro' might be treated in this manner, and the old channel converted into a tidal basin.

Care should be taken that the cuts should not cross the straight reaches if avoidable, as by that course double the number of dams would be required. It had been observed, that the second cut

in the Tees had diminished the tidal receptacle, but this was because the channel had been only partially improved; the standard sections of the river having been taken too high up (*i. e.* too small), and the seaward portions subsequently adjusted to them, and the consequence had been that the tidal volume, and the depth of water on the bar were diminished. Land water was an important agent in keeping open and determining the size of a tidal channel; when driven back by the flood tide, it occupied the upper end of it, and in times of freshes, it filled almost the whole length of the river, preventing the tidal-water from entering and depositing silt. Land water, while holding but little matter of its own in suspension, took up silt and conveyed it seaward.

Dredging, although an expensive process, must be resorted to, as an auxiliary, if the bed be composed of clay, and that irrespective of the question whether training walls or jetties should be adopted; and the material dredged should be used in the construction of training banks and for other similar purposes.

Jetties, he would remark, greatly disturbed currents, even when arranged in pairs; holes were scoured at their extremities, and resulted in the formation of sandbanks lower down; silt being particularly susceptible to the action of eddies. The formation of land between jetties was rather an objection than an advantage where tidal space was important; and jetties reduced but slightly the cost of breastworks. The materials for the construction of training banks would vary according to the situation in which the banks were to be placed: there were considerable advantages in the use of fascines. Training banks composed of slag-blocks were dangerous to vessels. Those at the mouth of the Ouse, in the Norfolk estuary, composed of clay mixed with brushwood, and covered with small-sized stones, had stood remarkably well, and were not dangerous; but training walls, whether situated in the channel, or at the mouth of a river, should not be carried much above the low-water line: those placed in the river should be backed with silt, forming a flat slope from the top of the bank to the brink of the river; the channel would thus be of large tidal capacity, and yet low tides would be confined to the proper course. Jetties were deficient in this respect. It was often well to make one wall much in advance of the other, especially if it was proposed to make great alterations in the channel, to give time to observe the effect of the change before the exact position of the second wall was determined. In some cases, if made slightly curved, one training wall placed on the concave side might permanently suffice. The protection for the slopes of rivers at the outfall might be effected by means of stone work, but layers of fascines should first be placed under the foot of the slope, to prevent undermining;

or protection might be entirely given by fascine-work with creosoted stakes, and renewed every four or five years, in which case the work need not be carried to the bottom of the slope or bed of the river. In cutting off wide bends, or 'slakes,' by training-banks, the work should be commenced at the up-stream end, and the down-stream end should not be closed till the 'slake' was warped up. This allowed a change of water at each tide, and promoted warping at the most rapid rate, besides avoiding the pressure of water at the back, and the probable rupture of the bank. The bottom layer of the bank should project considerably into the river channel, in order to prevent the whole from being undermined. Shipping berths were not quite consistent with the maintenance of a uniform channel; it would be generally better to adopt tidal basins, or floating docks along the margin of the river.

Mr. J. Scott Russell said he perfectly assented to the superiority of straight courses for rivers; in his former remarks he had merely intended to point out the evils which had arisen from the abrupt interpolation of portions of straight cuts into gently winding rivers already in a fixed condition, and also to show the practicability of improving a good navigable river without making it straight. If a continuous, straight and deep channel already existed, nothing could be better.

Mr. P. J. Messent said he wished to correct the statement, that the depth of water, on the bar of the Tees, was greater than existed on the bar of the Tyne. The depth of water on the bar of the Tyne at low water of ordinary spring tides was more than 15 feet, and at high water 31 feet; while at low water neap tides it was upwards of 17 feet.

Mr. Hawkshaw, Past-President, said it was, in all cases, extremely difficult to estimate, with accuracy, the comparative cost of works like those on the Clyde, the Dee, or the Tees. The diversity of circumstances attending the execution of them was so great, and the results were so seldom identical, that such a calculation could be of no practical utility.

The subject of the improvement of the Tees led to two points for consideration, one, which was perhaps the most important that could apply to tidal rivers, was, whether, by works such as those projected, anything could be done to remove the so-called bars of these rivers. It had been held as an axiom by many, and especially by nautical men, that there was no kind of works which could be devised, whereby these bars could be removed. Now, the Tees was a river where this experiment might be fairly tried. Bars were, he apprehended, caused by the meeting of two opposite currents, which, by neutralising each other, allowed the sedi-

mentary materials, which were carried with them, to be deposited at the point where those currents came into collision. Therefore, if so much energy could be imparted to one current that it should overcome the other, and deflect it to a given distance, the place of deposit would be removed in a corresponding degree. The mouth of the Tees was wide and trumpet-shaped, unlike the Mersey, which was bottle-shaped, with the neck outwards; this formation by permitting a large quantity of water to pass up, and flow out again, was the cause of the bar being forced back to a greater distance from the mouth of the river. Were it possible, by means of two groynes, so to contract the mouth of the Tees, that it should, to some extent, resemble that of the Mersey, then, the great quantity of water flowing out of the Tees, would have force enough to remove the bar, or, at least, to push the deposit into deep water.

Whether rivers were to be elongated, or shortened, and straightened, were matters of detail. It was quite certain, if the course of a river were shortened to the extent of diminishing its capacity for holding water, to that extent, the power which was necessary to remove the bar seawards would be diminished; therefore, when a bend in a river was cut off, the channel should be elongated upwards or deepened upwards to a corresponding extent, in order to admit the same amount of water.

The other question, with respect to the value of the fresh water in a river, was not easily solved. If, as in the Nile, the fresh water held the sediment, then, it was clear, no good result was effected by making it quiescent, and allowing the silt to be deposited in the bed of the river. The effect of this, was gradually to raise the bed of the river and to extend its delta. If, on the other hand, the fresh water was pure, and the sea water contained the deposit, other things being the same, more good might arise from the pure water flowing down, than from the muddy sea water flowing up the river. These problems did not admit of being solved by any one rule, but must be dealt with according to the nature of each particular case, and he hoped, in the case of the Tees, that the result of the treatment adopted, would be a considerable improvement to its navigation.

Mr. Taylor in reply said, he must claim the indulgence of the Institution, as having neither professional nor practical knowledge of this subject, he had merely furnished a record of his own observations. He had, however, been careful not to assert anything that had not come under his personal notice, during a period extending over most of the time when the works were in progress.

After so long a discussion, he would only refer to one or two matters of fact. The statement, that at the time the staiths for the Stockton and Darlington Railway Company were erected at Middlesbro', there was deep water along that shore, had been

questioned, as was also the statement that the silting up of these staiths had resulted from the action of the works in Bamblet's Bight. It had been asserted that there were shoals along that part of the Middlesbro' shore, and that the Company went to the wrong place to build their staiths. He recollected perfectly that before the staiths were built, ships came there to discharge cargoes, being unable otherwise to get up to Stockton; and it seemed opposed to common sense, that the Railway Company should place their staiths on the top of a shoal. In reply to his inquiries of the Harbour Master of the Tees on this subject, he had received a communication of which the substance was, that when the staiths were constructed, there was no shoal or obstruction to the regular working; that ships could lie for some distance above the staiths without inconvenience; that, had there been such a shoal, the Railway Company would never have erected the staiths there. The object in removing the shipping port lower down the river, to Middlesbro', was to get into deep water, and it was only through the operation of the works in Bamblet's Bight that the shipping berths became bad.

Again, to a further inquiry, as to the exact depth of water at the site of the staiths? the reply was, that when the erection of the staiths was begun, there was a depth of about 13¼ feet of water along the shore at low water, and ships used to lie there windbound, or waiting for filling up their cargoes from Stockton, and there was the same depth of water when the staiths were opened for work; but when the Navigation Company began their works in Bamblet's Bight, the berths gradually became shoaler, till at last, in 1836, there was only a pool at each berth, with sand projecting between.

With respect to the Table of the depths of water,—he did not question the accuracy of the figures, nor should he attempt to compete with the compiler as an authority; but those figures went no further than to Cargo Fleet, and it was below Cargo Fleet that the mischief was mainly done. In the Paper he had endeavoured to show, that the defect in the scheme of the Navigation Company was in neglecting the lower reach of the river; that while making a straight road up to Stockton, the river ran almost dry all the way below, as was shown by the statement of the Tees pilot, that "in 1852 he walked across the river on the shoals at low water."

In reviewing these works he would remark, that the first cut had the effect of saving a large bend of the river and getting rid of a shoal, thus deepening the water considerably. The second cut he thought much more doubtful, taking the whole scheme of the improvement of the river, and bearing in mind the amount of money to be spent, and the extent of the river to be dealt with. The cut was so little shorter than the reach it avoided that, in his

opinion, it was not worth the large cost at which it was carried out. The cost of the two cuts and works connected with them, saddled the Tees with a tonnage duty of 6*d*. per ton, amounting to £8,000 or £10,000 per annum, and the great hardship of the thing was, that the people of Middlesbro' had to pay for the works which were running the river dry after the cut was made. He thought too many groynes were put in, and he did not see the advantage of putting in any groynes in the narrow part of the river, inasmuch as that treatment shut out a large quantity of tidal water, and almost annihilated the scouring force of the ebb tide. Wattle jetties had been mentioned as having been put up in the Severn. He believed similar measures had been used in the first instance at Middlesbro', where the wattles were brought 18 inches above high water, and allowed the tide to flow freely through. He thought something of this kind would have been much cheaper and have answered the purpose better than close timber jetties, by serving to deflect the current, and at the same time allowing a large quantity of tidal water to come into the river. On the subject of the training walls formed of slag, he could give no opinion; the river had been converted into a canal, and must be treated accordingly. The practical result of the government of the river by the Navigation Company was that, in 1850, when the lower part of the river ran nearly dry, most of the ships had left the port; and the tonnage dues in 1850 were less than half those of 1846; and if it had not been for the discovery of the iron-stone permitting the inauguration of another system, the Tees would by this time nearly have ceased to be a port.

December 13, 1864.

CHARLES HUTTON GREGORY, Vice-President, in the Chair.

The discussion upon the Paper No. 1,115, "On the River Tees," &c., occupied the whole of the evening, to the exclusion of any other subject.

Level Supported upon a Gimbal Joint.

After the Meeting, Mr. F. B. Doering exhibited and explained a Level which, for readier adjustment, was supported upon a gimbal joint, instead of on parallel plates; and he stated that the plan was applicable to other Surveying instruments. The method was similar to that adopted for a ship's compass, with the addition of vertical arcs, at right angles to each respective axis, which were clamped to each other and to the frame that was screwed on to the ordinary tripod stand. In the field, when using this instrument, however uneven the ground might be, the legs were put down in the most convenient manner irrespective of level. The clamps holding the telescope rigid with the stand were then slackened, and the telescope set approximately level by hand. The clamping screws were then tightened. and the final adjustment was effected by two tangent screws at right angles to one another, and connected respectively with each arc at the clamps. On moderately level and firm ground, it was not necessary to unclamp the joint of the instrument; as it might be set up approximately level in the ordinary way by the legs, and be brought to a perfect adjustment at once by the tangent screws. By dividing one of the arcs into degrees, the instrument could be used for measuring vertical angles, and thus the height of any point at a distance, required for checking, might be obtained. It was believed that, by this method, a level could be set up on sidelong, soft, or broken ground, with as much ease as on firm, level ground; and that, as none of the movable parts were liable to become jammed, as in the parallel plate system, a more perfect adjustment was practicable. A level constructed in this manner had been tried in wet weather and during high winds, and proved to be as steady as any instrument hitherto made.

ANNUAL GENERAL MEETING.

December 20, 1864.

JOHN FOWLER, Vice-President,
in the Chair.

Messrs. T. O. Donaldson, J. N. Douglass, and J. Thomson, were requested to act as Scrutineers of the Ballot, for the election of the President, Vice-Presidents, and other Members and Associates of Council.

The list of the attendances of the Members of Council for the past year was read, and the Ballot was commenced; the balloting-papers being sent for examination at intervals of fifteen minutes, in order to expedite the labours of the Scrutineers.

Resolved,—That, in future, a copy of the list of the attendances of the Members of Council be sent to all the Members of the Institution before the Annual General Meeting.

The Annual Report of the Council, on the proceedings of the Institution during the past year, was read.

Resolved,—That the Report of the Council be received and approved; and that it be referred to the Council, to be printed and circulated with the Minutes of Proceedings in the usual manner.

Resolved,—That this Meeting entirely approves of the measures which have been taken by the Council for establishing a Benevolent Fund for the benefit of the profession, and requests the new Council to afford such support and assistance as they consider they can properly give to the furtherance of so desirable an object.

Resolved,—That the cordial thanks of the Institution of Civil Engineers be given to Mr. F. J. Bramwell, Member, for the kindness and professional feeling which has led him to originate a Benevolent Fund for the benefit of the profession, and for the zeal and ability shown in his successful efforts to promote its establishment.

Mr. Bramwell returned thanks.

Resolved,—That the thanks of the Institution are due, and are presented to Messrs. J. V. N. Bazalgette, and T. Marr Johnson, for the readiness with which they undertook the office of Auditors of Accounts, and for the clear statement which they have laid before the Meeting; and that Messrs. T. Marr Johnson and F. W.

Sheilds be requested to undertake the office of Auditors for the ensuing year.

The Telford and Watt Medals, and the Telford and Manby Premiums of Books, which had been awarded, were presented.

Resolved, — That the thanks of the Institution are due and are presented to the Vice-Presidents and other Members of Council, for their co-operation with the President, their constant attendance at the Meetings, and their zeal on behalf of the Institution.

Mr. Gregory, V.P., and Mr. Hawksley, V.P., returned thanks.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Mr. M'Clean, President, for his strenuous efforts in the interests of the Institution, for his extraordinary attention to the duties of his office, and for the urbanity he has at all times displayed in the Chair.

Mr. Fowler, V.P., returned thanks, in the unavoidable absence of the President.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Mr. Charles Manby, the Honorary Secretary, and to Mr. James Forrest, the Secretary, for their constant zeal and devotion to the interests of the Institution, the ability displayed by them in the execution of their duties, and their attention to the individual wishes of the Members.

Mr. Manby and Mr. Forrest severally returned thanks.

The Ballot having been open more than an hour, the Scrutineers, after examining the Papers, announced that the following gentlemen were duly elected to fill the several offices in the Council for the ensuing year:—

President.

JOHN ROBINSON M'CLEAN.

Vice-Presidents.

John Fowler.
Charles Hutton Gregory.
Thomas Hawksley.
John Scott Russell, F.R.S.

Other Members of Council.

Members.

Sir W. G. Armstrong, C.B., F.R.S.
William Henry Barlow, F.R.S.
Nathaniel Beardmore.
Joseph Cubitt.
Thomas Elliot Harrison.
George Willoughby Hemans.
John Murray.
George Robert Stephenson.
Charles Vignoles, F.R.S.
Joseph Whitworth, F.R.S.

Associates.

John Aird, Jun.
Alexander Ogilvie.

Resolved,—That the thanks of the Meeting be given to Messrs. T. O. Donaldson, J. N. Douglass, and J. Thomson, the Scrutineers, for the promptitude and efficiency with which they have performed the duties of their office; and that the ballot-papers be destroyed.

ANNUAL REPORT.

Session 1864-65.

In laying before you an account of the proceedings of the Institution during the past twelve months, the Council have to report, that the characteristic feature of steady, progressive development, was never more fully exemplified, in any similar period, since its first establishment. You are aware how attractive the Meetings have proved, how well the discussions have been sustained, how rich the library is fast becoming in all professional and scientific works of this and other countries, how greatly the number of Members and Associates has increased, and, generally, how satisfactory is the financial condition. The importance to every Engineer of being connected with the Institution is now more generally felt; and although the time has not yet arrived, when it is considered imperative for every one practising the profession to have received the diploma of the Institution, yet in general opinion it may be said, that an equivalent position has been attained. On these grounds, therefore, it is more than ever essential, that the qualifications of all candidates for admission should be scrupulously examined; and that the Members should satisfy themselves, from personal knowledge, before signing any Proposition Paper, that the person so recommended possesses such character, practice, and experience as to entitle him to the distinction he seeks.

The Papers read during the Session were:—"Description of Lighthouses lately erected in the Red Sea," by W. Parkes, (M. Inst. C.E.); "On the Duty of Cornish Pumping Engines," by W. Morshead, junior; "On the Closing of Reclamation Banks," by J. M. Heppel, (M. Inst. C.E.); "The East Coast, between the Thames and the Wash Estuaries," by J. B. Redman, (M. Inst. C.E.); "The Actual State of the Works on the Mont Cenis Tunnel, and Description of the Machinery employed," by T. Sopwith, junior, (Assoc. Inst. C.E.); "On the Resistances to Bodies passing through water," by G. H. Phipps, (M. Inst. C.E.); "Description of the Santiago and Valparaiso Railway, Chilé, South America; with remarks upon resistances from curves on railways, and upon coal-burning locomotives," by W. Lloyd,

(M. Inst. C.E.); "On the Structure of Locomotive Engines for ascending steep inclines, especially when in conjunction with sharp curves on railways," by J. Cross; "On the Impedimental Friction between Wheel Tires, and Rails, with plans for improvement," by W. B. Adams; "On the Means of Utilizing the products of the Distillation of Coal, so as to reduce the price of Coke; with descriptions of the ovens, and of the best processes in use in Great Britain and on the Continent," by M. Pernolet, (of Paris); and "On the Machinery employed in sinking Artesian Wells on the Continent," by G. R. Burnell, F.G.S.

The following Telford and Watt Medals, and Telford and Manby Premiums of Books, have been awarded to the Authors of some of these communications :—

1. A Telford Medal, and the Manby Premium, in Books, to George Henry Phipps, M. Inst. C.E., for his Paper, "On the Resistances to Bodies passing through Water."

*2. A Telford Premium, in Books, to John Baldry Redman, M. Inst. C.E., for his Paper on "The East Coast, between the Thames and the Wash Estuaries."

3. A Telford Medal, and a Telford Premium, in Books, to William Lloyd, M. Inst. C.E., for his "Description of the Santiago and Valparaiso Railway, Chilé, South America; with remarks upon resistances from Curves on Railways, and upon Coal-burning Locomotives."

*4. A Telford Premium in Books, to William Parkes, M. Inst. C.E., for his "Description of Lighthouses lately erected in the Red Sea."

5. A Telford Medal, to M. Pernolet (of Paris), for his Paper "On the means of utilizing the products of the Distillation of Coal, so as to reduce the Price of Coke; with a description of the Ovens, and of the best processes in use in Great Britain and on the Continent."

6. A Watt Medal, and a Telford Premium, in Books, to Thomas Sopwith, jun., Assoc. Inst. C.E., for his Paper "On the Actual State of the Works on the Mont Cenis Tunnel, Victor Emmanuel Railway, and Description of the Machinery employed."

*7. A Watt Medal, to William Bridges Adams, for his Paper "On the Impedimental Friction between Wheel Tires and Rails, with plans for Improvement."

8. A Watt Medal, to James Cross, for his Paper "On the structure of Locomotive Engines for ascending Steep Inclines, especially when in conjunction with Sharp Curves on Railways."

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* Have previously received Telford Medals.

*9. A Telford Premium, in Books, to John Mortimer Heppel, M. Inst. C.E., for his Paper "On the Closing of Reclamation Banks."

10. A Telford Premium, in Books, to George Rowdon Burnell, F.G.S., for his Paper "On the Machinery employed in sinking Artesian Wells on the Continent."

The inquiry undertaken by Mr. Phipps, "On the Resistances to Bodies passing though Water," was a carefully-conducted and an elaborate scientific investigation into the causes which influence High Speed Steam Navigation. It was contended that the larger amount, by far, of these resistances was that due to friction, and that no modifications of 'form' could have much effect in diminishing the total resistance. The methods adopted by different authorities, for the determination of the coefficient of friction, were minutely examined, and the deductions drawn in the Paper were illustrated by reference to two large steam-vessels, the speed and other properties of which were known—the 'Leinster,' Holyhead mail packet, and the 'Atrato,' belonging to the Royal West India Mail Navigation Company.

In the Paper by Mr. Redman, the peculiarities of "The East Coast, between the Thames and the Wash Estuaries," were described, including the well-known formations termed the Nesses, caused by the constant abrasion of the neighbouring cliffs, due to the influence of wind waves, produced by gales from the N.E., acting on the large area of the North Sea. It stated that Landguard Point might be regarded as the shingle end of the eastern beaches, whose leeward motion was the reverse of that of the beaches of the English Channel, and that its accretion threatened the very existence, ultimately, of Harwich Harbour, as a deep-water port. The object of this communication, like the one on the South Coast presented in 1852, of which it was a continuation, was to describe the characteristics of a range of coast within certain limits, to trace the changes produced by constant natural causes, and the resultant influences on the various harbours of Harwich, Orford, Southwold, Yarmouth, Blakeney, Wells, and Brancaster, which were mainly dependent on the barriers that had been alluded to. At Yarmouth, by judiciously constructed works, a material improvement had been effected; while at Orford, where no assistance was rendered, great changes had occurred. At Harwich, from constant progressive changes, it was difficult to speculate on the ultimate result of the continued operation of natural agencies, unchecked by works of a conservative character.

The physical features of the Republic of Chilé, South America,

* Has previously received a Telford medal.

were well portrayed in Mr. Lloyd's communication, "Description of the Santiago and Valparaiso railway;" from which it appeared that, although the extreme width of the country seldom exceeded in any part 100 miles, yet there was a difference of level of about 20,000 feet. Being also constantly liable to terrestrial disturbances, and not overburthened with pecuniary resources, the mode of carrying out such enterprises was a very interesting study. The distance in a direct line from the capital to the chief port was only about 70 miles, but the length of the railway between the two places was 114 miles. The principal work upon it was the Tabon Incline. This was 12 miles in length, with an average rise, throughout, of 1 in $46\frac{1}{2}$, and upwards of one-half of it was curved. The maximum gradient was 1 in $44\frac{1}{2}$ for a distance of $3\frac{1}{2}$ miles, combined with curves of 604 feet radius for an aggregate length of $1\frac{1}{2}$ mile. The railway was carried along the abrupt and rugged sides of the mountains, at an elevation of 300 feet above the valley, the rocks towering above to an altitude of nearly 1,000 feet. The results of a few imperfect experiments, to ascertain the resistances of sharp curves in combination with steep gradients, showed that upon a gradient of 1 in 50, the resistances amounted to 55 lbs. per ton of train when the line was straight, and to 70 lbs. per ton of train upon curves of 600 feet radius. Further, that upon a curve of 1,000 feet radius, the resistance was double that upon a straight line; and upon a curve of 600 feet radius, it was equal to the gravity upon an inclined plane of 1 in 150. It had been found, by experience, that the application of a jet of hot water upon the flanges of the leading wheels of the engines facilitated their passage round sharp curves, while moisture applied to the rails from the tender, the rails for the engine remaining dry, sensibly reduced the resistances due to curvature.

It was argued, that as trade and navigation extended, the necessity of providing safeguards, on what had been termed the "great highway of nations," led to the erection of works in comparatively inaccessible and remote regions, where the means at the disposal of the Engineer were extremely limited. He had frequently to design such structures, as, while giving a reasonable prospect of permanence, should combine the smallest quantity and weight of material, and be capable of being put together on the spot with the least amount of labour. This was especially the case in the construction of lighthouses, as they were often required to be built on isolated and barren rocks, or shoals, the approach to which might be at all times difficult and dangerous, and were at times impracticable. These points determined, more or less, the details of the works which formed the subject of Mr. Parkes' "Description of Lighthouses lately erected in the Red Sea" for

the purpose of facilitating the navigation of the northern portion of that inlet of the ocean. The sites selected by the Author were Zafarana Point, on the Egyptian mainland, where a tower of rubble-stone was built, and the Ushruffee and Dædalus submerged coral-reefs, where a wrought-iron framework, supported on teak piles, resting on and imbedded in concrete, brought up above the level of high water was adopted. The wrought-iron framework was filled in with corrugated iron, so as to form a series of rooms one above the other, as a central column, with verandahs, or galleries, round each room, likewise partially enclosed, by which a portion, at least, of the sun's rays was prevented from falling on the walls of the rooms, while at the same time permitting a free admission of air. The details of construction were minutely entered into, followed by a succinct narrative of the operation of erecting the structures, at a distance of 3,000 miles from Great Britain, from whence all the materials were obtained.

"The Means of utilizing the Products of the Distillation of Coal, so as to reduce the Price of Coke," brought forward by M. Pernolet (of Paris), were described to consist in the employment of such a form of oven as enabled every product of the distillation to be turned to account, while still giving to the coke all the solidity, density, and lustre that distinguished good coke made in the ordinary way. It was stated that this was principally effected, by keeping the coal from all contact with the air during its distillation, by performing that process very slowly, and by collecting and condensing the volatile products. It was asserted that the results due to these arrangements were, a larger yield of coke, and the collection of all the tar, the ammoniacal liquors, and the gas which would be obtained from the same coal, if distilled in the retorts of a gas manufactory.

Perhaps the most interesting, and possibly the most important work in Civil Engineering in the present day, is that undertaken for piercing the great barrier of the Alps, so as to put France and Italy in direct railway communication. It was therefore with great satisfaction, that a Paper was received from Mr. T. Sopwith, jun., "On the Actual State of the Works on the Mont Cenis Tunnel, Victor Emmanuel Railway, with a description of the Machinery employed." The ends only being available for attack, and the length being about $7\frac{6}{10}$ miles, it was obviously of importance to devise such expedients as would facilitate the progress of the works beyond what was possible by hand-labour. M. Sommeiller, the Engineer-in-chief, proposed to use compressed air for driving the machinery, and he calculated that on its escape, a volume of fresh air would be supplied, adequate to the requirements of the workmen. The result was most successful and encouraging, for a machine had been produced, which could pierce a

common bore-hole, about $1\frac{1}{4}$ inch diameter, and 3 feet deep, into the rock in twenty minutes, where two miners would have taken two hours. Eleven of these machines were carried on one frame, and were employed in driving the advanced gallery 10 feet square; the compressed air being used at a pressure of five atmospheres above atmospheric pressure. At the same rate of progress at both ends as had been obtained at the Modane end in June 1863, the tunnel might be completed in about six years and a half; but M. Sommeiller confidently expected, that such improvements would be made as to enable the work to be finished in less than five years from the date named. These anticipations had, it was believed, been to some extent realized since the period of Mr. Sopwith's visit.

In Mr. Cross's Paper, "On the Structure of Locomotive Engines for ascending Steep Inclines, especially when in conjunction with sharp curves on Railways," a description was given of an engine fitted with Adams' radial axle-boxes and spring-tires, which had been built for use on the St. Helens' line. The engine was on eight wheels, with a rigid wheel base of 8 feet only, being the distance between the centres of the coupled wheels, while the actual wheel base was 22 feet. When the engine was moving at high velocities, the boxes had an incessant lateral vibration. It was constructed to traverse curves of 200 feet radius, but it had gone round one of 132 feet radius, and was then free from all jerking motion; was perfectly steady at 60 miles an hour on straight lines, without a train attached; and had taken seven carriages, with a load weighing 72 tons up a gradient of 1 in 36, combined with a curve of 440 feet radius.

The discussion upon this Paper was taken in conjunction with that upon a relative communication by Mr. Adams, "On the Impedimental Friction between Wheel-Tires and Rails," in which it was urged, that the best mode of preventing the blows and friction between the wheel-tires and the rails, and consequent jumping and sliding, was to provide for elastic resilience immediately over the tire beneath the wheel, and immediately under the rail. This had been accomplished on the North London line, by laying longitudinal timbers on the ordinary cross-sleepers, and placing the rail-supports between the cross-sleepers; the latter being packed, and the longitudinals being unpacked, so as to yield elastic action. Also, by applying a hoop spring of tempered steel between the wheel and the tire, enabling the tire to slip round the wheel, or the wheel to slip within the tire, and the tire slightly to flatten in the case of driving-wheels, and to rock laterally to fit an unequal surface of rail. These results had been verified on the North London and the St. Helens' lines, where common tires under elastic use had exceeded in durability the best steel.

The purpose which Mr. Heppel had in view in his Paper "On the Closing of Reclamation Banks," was to bring clearly into notice the circumstances which determine the velocities of influx and efflux, and consequent scour, attendant on the closing of embankments for reclaiming land from the sea, or from a tideway, and constituting the chief difficulty to be overcome in executing such works. It was an attempt to elucidate a question incapable of being expressed by formulæ, and was a mode of treating geometrically that which could not be dealt with analytically. In the course of the discussion it was remarked, that the method of graphic integration adopted by the Author, for calculating the pressures which would come upon the breach, and of tentatively ascertaining the laws which regulated the rise and fall of the water, seemed, to some extent, to get rid of the mathematical difficulties of the case.

In the last Paper of the Session, "On the Machinery employed in Sinking Artesian Wells on the Continent," by Mr. Burnell, a short account was given of the well at the Abattoir of Grenelle, as well as of that at Passy, where important modifications of the various mechanical processes were adopted. The different systems of well-boring were divided into three classes:—the Chinese, or M. Fauvelle's; the French, or rather the usual well-borer's plan; and M. Kind's,—as dependent mostly on the nature of the tools. It was stated that the first plan had been almost universally abandoned; that in the second, when the excavation was deep, the weight of the tools and of the solid iron rods caused considerable difficulty in transmitting the blow of the tool; and that now hollow iron rods were used, while the striking part, for comminuting the rock, was made to slide, by M. Œuyenhausen's joint, which permitted the tool to fall freely through a certain distance, and thus to avoid a jar. The plans adopted by M. Kind in the well at Passy were then minutely detailed.

With regard to the publication of the Minutes of Proceedings, in which there has been an unavoidable delay, it must be explained, that the present system and organization are such as to render the regular issue of these volumes dependent, not upon the efforts of one or two individuals, but upon all who either write Papers, take part in the discussions, or are invited to assist in furnishing materials for the biographical notices of deceased members, which it has been the custom to give in each volume. The care which it has heretofore been considered advisable to bestow in the preparation of these records of the business at the Meetings involves sending first the MS., and afterwards a proof to each contributor, and the omission of the return of one of these, obviously prevents the completion of any article; while the time occupied in these several processes is such as seriously to add to the labour of collating and reading for the press. There will, however, be

shortly issued Volumes XXI. and XXII. of the Minutes of Proceedings.

The General Index to the series of Volumes from I. to XX., inclusive (in itself a volume of about four hundred pages), is also nearly ready. In its preparation, much time and labour have necessarily been expended; for although partially based on the indices accompanying each volume, all the name entries have had to be re-modelled, while the subject-matter entries required to be re-classified. One alphabetical arrangement has been preserved throughout, and every expedient has been adopted for facilitating reference. The value of this compilation to the profession, especially to the younger Members, can scarcely be overrated; for it will afford a key to the accumulated mass of information contained in these volumes, hitherto, for want of a General Index, not so available as could have been desired. Moreover, this General Index will enable the views of the different Members on any particular subject to be readily ascertained; and it will serve to show to whom the Institution and the profession are indebted, for thus imparting the results of their practical experience. It will likewise have the effect of indicating on what particular topics information is still wanting, so as to render these records a complete exposition of engineering science. Beyond this, as well as being an index to the contents of these twenty volumes, it may be taken advantage of, as a basis of a classified synopsis of technical knowledge.

With a view of making the Library still more useful and accessible to the members, Mr. Henry Storks Eaton, M.A., has been appointed Assistant to the Secretary, for the special purpose of taking under his charge the care of the books, and of completing the Catalogue of the collection, in continuation of that issued in 1851,—now out of print. A new edition of the Catalogue will shortly be ready for distribution to the members. At the date of the publication of the previous Catalogue, the library contained upwards of three thousand volumes, besides fifteen hundred tracts; now there are about five thousand five hundred volumes, and three thousand tracts. During the last fifteen years, while the Transactions of Societies and the serials have contributed to swell the number of volumes, there have also been added many separate treatises, particulary by French and German authors. The Library Committee are most anxious that the Members should point out any deficiences they may observe, from time to time, in order that these may be supplied. This suggestion is especially addressed to those members whose occupations lead them to visit foreign countries, as it is earnestly desired that there may be available in the Institution, for consultation and reference, a copy of every work bearing on the profession, wherever produced.

On the occasion of the Annual Dinner, the Institution had the privilege to receive as guests, and to be addressed by many distinguished men, the career of several of whom has been so identified with the advance of Engineering science and of public works, as to increase the pleasure given by their presence. The Council trust that, in inviting such guests, they but gave expression to your wishes, and that, in the future, these social gatherings will continue to be regarded as an important feature in your proceedings.

The tabular statement of the transfers, elections, deceases, and resignations of members of all classes, during the years 1862-63, and 1863-64 (taking into consideration the names which have been erased from the Register), appears thus:—

—	Honorary Members.	Members.	Associates.	Graduates.	Annual Increase.
1862-63.					
Transferred to Members .	..	..	5	1	
Elections	..	25	49	..	74 − 34 = 40
Deceases	2	9	15	..	
Resignations	..	1	4	..	34
Erased from the Register . .	..	..	3	..	
1863-64.					
Transferred to Members . .	..	..	13	..	
Elections	..	32	61	..	93 − 38 = 55
Deceases	..	16	9	..	
Resignations	..	1	4	1	38
Erased from the Register. .	..	2	5	..	
Members of all Classes on the Books, November 30, 1864.	18	452	617	8	1,095

This is an increase of about 5·3 per cent. in the past twelve months.

If the Honorary Members and Graduates are omitted from this calculation, the annual increase of Members and Associates stands thus:—

Years.	Members Elected.	Associates Elected.	Total Elected.	Deceases, Resignations, and Erasures.	Effective Increase.
1859	16	41	57	20	37
1860	23	39	62	25	37
1861	24	45	69	49	20
1862	35	37	72	15	57
1863	25	49	74	32	42
1864	32	61	93	37	56

The following Member, Associates, and Graduate, having tendered their resignations, have been permitted to retire from the Institution :—Eugène Flachat, Member; John Dickinson, William Thompson Grant, William Malins, and Thomas Burdett Turton, Associates; and John Salkeld, Graduate.

The deceases announced during the year have been: Francis Baird, Thomas Bartlett, John George Bodmer, Thomas Casebourne, Charles Dean, Joseph Gibbs, George Hurwood, James Jones, Rhys William Jones, Edward Oliver Manby, George Meredith, George Mackay Miller, William Chadwell Mylne, Richard Roberts, William Simpson, and Adam Smith, Members; John Staines Atkinson, William Bagnall, Frederick Lawrence, William Llewellin, Thomas Telford Mitchell, Robert Ransome, Charles Frederick Stuart Smith, Alfred Thompson, and Arthur Wightman, Associates.

The memoirs of some of our late friends will be given in an Appendix to this volume. The list includes the names of some very old Members, several of whom were engaged under the first President, Mr. Telford, as well as one of the six founders of the Institution—Mr. James Jones,—who, in its early days, acted as Secretary, and whose death, at an advanced age, was the result of a lamentable accident.

The Abstract of the Receipts and Expenditure for the year ending the 30th of November last, as prepared by the Auditors, shows that the payments during the last twelve months have amounted to £2,955, against receipts from all sources of £4,414; and that the amount obtained from subscriptions and fees alone, without including the dividends upon investments and the sums derived from other sources, has exceeded the disbursements by about £450. The Council have, therefore, been again enabled to add to the Institution Fund, by the purchase of £1,000 Four per Cent. Debenture Stock of the London, Brighton, and South Coast Railway Company. On comparing this statement of accounts with the average of the previous ten years, it appears that the total income now exceeds that average by nearly 40 per cent., while the increase in the disbursements during the same period has been less than 20 per cent.

The funds of the Institution now consist of:—

I. General Funds.

	£.	s.	d.	£.	s.	d.
1. Stephenson Bequest—North Eastern Railway Company Four per Cent. Debenture Stock	2,000	0	0			
2. Miller Bequest—Reduced Three per Cent. Annuities	2,133	6	8			
3. Errington Bequest—Great Northern Railway Company Four per Cent. Debenture Stock	1,000	0	0			
Carried forward .	£5,133	6	8			

	£.	s.	d.	£.	s.	d.	£.	s.	d.
Brought forward . . .				5,133	6	8			
4. Institution Investments—Great Eastern Railway Company, Norfolk Four per Cent. Debenture Stock	2,000	0	0						
„ Great Northern ditto .	500	0	0						
„ London and North Western ditto . .	1,000	0	0						
„ London, Brighton, and South Coast ditto	1,000	0	0						
				4,500	0	0			
5. Cash in the hands of the Treasurer	1,124	3	2						
„ „ Secretary	62	3	0						
				1,186	6	2			
							10,819	12	10
II. Building Fund.									
1. Great Northern Railway Company Four per Cent. Debenture Stock				500	0	0			
2. London and North Western ditto. . . .				500	0	0			
3. On Deposit at the Union Bank				751	0	1			
							1,751	0	1
III. Trust Funds.									
1. Telford Fund—									
Three per Cent. Consols .	2,551	15	10						
„ „ Annuities.	2,342	17	1						
				4,894	12	11			
Unexpended Dividends, Three per Cent. Consols				1,775	19	8			
2. Manby Donation—Great Eastern Railway Company, Five per Cent. Stock . . .				200	0	0			
3. Miller Fund—Lancashire and Yorkshire Railway Company Four per Cent. Stock .				2,000	0	0			
„ Great Eastern Railway Company, Norfolk, ditto				1,100	0	0			
							£9,970	12	7

Together amounting to £22,541. 5*s.* 6*d.*, as against £20,649. 16*s.* 2*d.* at the date of the last Report.

The propriety of establishing a Benevolent Fund in connection with the profession received the serious consideration of the Council before any steps were taken to ascertain the views of the members generally. It was well pointed out by Mr. F. J. Bramwell, M. Inst. C.E., with whom the present proposal originated, and to whom your cordial and hearty thanks are especially due, that in most, if not in all, other professions and occupations, there was a regularly organized system for the aid of decayed members, and of their families when in necessitous circumstances; and that, inasmuch as the Civil Engineers were already a numerous and an increasing body, in some respects more liable to those misfortunes and vicissitudes which were known by experience to overtake those following other pursuits, it was incumbent on the profession, that some business-like action should be taken, in preference to soliciting subscriptions for individual cases, unfortunately found to be frequently requisite of late. Pri-

vate inquiries among a few of the members of the Institution having shown that such a fund, if properly managed and adequately supported, could not fail to be productive of great good, it was determined to appeal to the general body, and the result has been such a response as fully to justify the course which has been pursued. Already, from 224 contributors, donations to the amount of £21,884, and annual subscriptions to the extent of £487, have been promised. Of these contributors 97 are donors only, 14 are both donors and annual subscribers, and 113 are annual subscribers alone.

At the Meeting recently held in the rooms of the Institution, the Fund was formally established, and that portion of the General Committee which it was recommended should be elected by the contributors was appointed. At the same time, the Committee was requested to prepare a scheme, with bye-laws and rules, for the administration of the Fund, and to report the result of their deliberations, to a General Meeting of the contributors, to be summoned for the 17th of January next. The Council will not venture to anticipate what may be the issue of the considerations of the Committee; but they feel assured, that a measure so calculated to enhance the character of the profession will be cordially supported, and on every ground they commend it to the favourable notice of the Members.

The amount of arrears of subscriptions for 1864, still remaining due on the 30th of November, is:—

	£.	s.	d.	£.	s.	d.
From members of all classes, residing abroad .	55	2	6			
From members of all classes, residing in the United Kingdom	177	19	6			
				233	2	0

The amount of arrears for the years 1862 and 1863 is—

From members of all classes, residing abroad .	40	19	0			
From members of all classes, residing in the United Kingdom	76	2	6			
				117	1	6
Total				£350	3	6

In this statement, no notice is taken of the subscriptions of any member who is more than three years in arrear, including the current year. The Council, however, usually retain the names on the books as long as possible, not wishing unduly to press upon any member who may at the moment be unable to continue his subscriptions with punctuality. Some of these arrears are ultimately recovered, and the members remain connected with the Institution. On rare occasions the Council exercise the privileges granted in the Bye-laws, by entering the name of some old member of the

profession as a Life Subscriber. Still it has been found necessary, in accordance with the provisions of Clause 10, Section V., of the Bye-laws, to erase the names of seven Members and Associates from the Register of the Institution. Every attention continues to be given to the collection of the Subscriptions, to avoid, as far as possible, the accumulation of arrears.

In the Balloting List, the names of the present President, Vice-Presidents, and Members of Council, being eligible, again appear, in conjunction with the names of Messrs. Abernethy and Brunlees, Members, and of Messrs. J. Aird, jun., A. Ogilvie, T. T. Bury, and J. Freeman, Associates, to complete the number required by the Rules, and all of whom have consented to act if elected.

If the mission of the Civil Engineer be, as described in the Charter of Incorporation, "the art of directing the great sources of power in Nature for the use and convenience of man—as the means of production and of traffic in states, both for external and internal trade—as applied in the construction of roads, bridges, aqueducts, canals, river navigation, and docks, for internal intercourse and exchange; and in the construction of ports, harbours, moles, breakwaters, and lighthouses; and in the art of navigation by artificial power for the purposes of commerce; and in the construction and adaptation of machinery; and in the drainage of cities and towns"—if this be the object of our profession, it may fairly be asked what other calling plays so large a part in developing the material resources of the world, and in facilitating that intercourse between nations which tend to promote peace and goodwill. Let all, then, endeavour to render this Institution the depository of the accumulated knowledge and experience of our members; and let all strive to sustain and consolidate this Institution, so that it may continue truly and faithfully to represent the important interests committed to the care of the Civil Engineer.

ABSTRACT *of* RECEIPTS *and* EXPENDITURE.

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS.

Dr.	£.	*s.*	*d.*	£.	*s.*	*d.*
To Balance of Petty Cash, Dec. 1, 1863, in the hands of the Secretary	56	16	1			
— Balance in the hands of the Treasurer	666	17	11			
				723	14	0
— Subscriptions and Fees :—						
Arrears	254	3	6			
Current	2,750	9	6			
Subscription, 1865 (in advance)	12	7	0			
Fees	289	16	0			
Life	89	15	6			
				3,396	11	6
— Publication Fund				58	16	0
— Council Fund				52	10	0
— Publications :—Sale of Transactions				135	11	10
— Telford Fund :—						
Dividends—1 year, on £2,551. 15*s.* 10*d*, Three per Cent. Reduced Consols	74	9	2			
Ditto, on £2,342. 17*s.* 1*d*., Three per Cent. Reduced Annuities	68	7	9			
Ditto, on £1,775. 19*s.* 8*d*., Three per Cent. Reduced Annuities	51	17	1			
				194	14	0
— Telford Premiums :—Repayment of excess of cost of binding, &c.				6	11	3
— Manby Premium :—						
Dividends—1 year, on £200, Great Eastern Railway Company, Norfolk Five per Cent. Preference Stock				9	14	4
— Stephenson Bequest :—						
Dividends—1 year, on £2,000, North Eastern Railway Company, Four per Cent. Stock				77	15	0
— Miller Fund :—						
Dividends—1 year, on £2,000, Lancashire and Yorkshire Railway Company, Four per Cent. Stock	77	15	0			
Ditto, on £1,100, Great Eastern Railway Company, Norfolk Four per Cent. Stock	42	15	10			
				120	10	10
— Miller Bequest :—						
Dividends—1 year, on £2,133. 6*s.* 8*d*., Three per Cent. Reduced Annuities				62	5	4
— Errington Bequest —						
Dividends—1 year, on £1,000, Great Northern Railway Company, Four per Cent. Stock				38	17	6
— Institution Investments :—						
Dividends—1 year, on £2,000, Great Eastern Railway Company, Norfolk Four per Cent. Stock	77	15	10			
Ditto, on £500, Great Northern Railway Company, Four per Cent. Stock	19	8	9			
Ditto, on £1,000, London and North Western Railway Company, Four per Cent. Stock	38	17	6			
Ditto, ½ year, on £1,000, London, Brighton, and South Coast Railway Company, Four per Cent. Stock	19	9	2			
				155	11	3
— Botfield Bequest				28	0	0
— Special Donation				50	0	0
— Donations to Library				15	0	0
— Sale of Old Iron, &c.				12	9	1
				£5,138	11	11

from the 1ST DEC., 1863, *to the* 30TH NOV., 1864.

PAYMENTS.

Cr.	£.	s.	d.	£.	s.	d.
By House, Great George Street:—						
Rent	364	1	3			
Rates and Taxes	43	4	2			
Insurance	18	19	9			
				426	5	2
— Salaries				562	10	0
— Clerks, Messengers, and Housekeeper				278	10	9
— Postage and Parcels:—						
Postage	32	16	6			
Parcels	2	7	7			
				35	4	1
— Stationery, Engraving, Printing Cards, Circulars, &c.				72	12	6
— Coals, Candles, Oil, and Gas:—						
Coals	18	0	0			
Candles	0	6	5			
Oil	1	7	0			
Gas	28	6	9			
				48	0	2
— Tea and Coffee				30	9	1
— Library:—						
Books	188	1	8			
Periodicals	18	16	0			
Binding Books	65	0	0			
				271	17	8
— Publication, Minutes of Proceedings				872	16	1
— Index to Minutes of Proceedings, Vols. I. to XX.				125	0	0
— Telford Premiums				97	10	3
— Watt Medal				2	8	0
— Manby Premium				3	11	6
— Diplomas				22	6	0
— Manuscripts, Original Papers, and Drawings				1	1	4
— Winding and Repairing Clocks				3	13	6
— Annual Dinner				45	0	11
— Incidental Expenses:—						
Christmas Gifts	2	4	0			
Occasional Assistance	6	13	0			
Assistance at Meetings	8	8	0			
Beating Carpets	3	7	6			
Household Utensils, Repairs, and Expenses	35	6	3			
				55	18	9
				£2,954	15	9
— London, Brighton, and South Coast Railway Company, £1,000 Four per Cent. Debenture Stock				997	10	0
— Balance of Petty Cash, Dec. 1, 1864, in the hands of the Secretary				62	3	0
— Balance in the hands of the Treasurer				1,124	3	2
				£5,138	11	11

Examined and Compared the above Account with the Vouchers and the Cash Book, and find this Account to be correct, leaving a Balance in the hands of the Treasurer of Eleven Hundred and Twenty-four Pounds, Three Shillings, and Two Pence.—November 30, 1864.

(Signed) JOHN V. N. BAZALGETTE, T. MARR JOHNSON, JAMES FORREST, *Auditors.* *Secretary.*

December 12th, 1864.

PREMIUMS AWARDED.

Session 1863-64.

The Council of the Institution of Civil Engineers have awarded the following Premiums:—

1. A Telford Medal, and the Manby Premium, in Books, to George Henry Phipps, M. Inst. C.E., for his Paper "On the Resistances to Bodies passing through Water."

*2. A Telford Premium, in Books, to John Baldry Redman, M. Inst. C.E., for his Paper on "The East Coast, between the Thames and the Wash Estuaries."

3. A Telford Medal, and a Telford Premium, in Books, to William Lloyd, M. Inst. C.E., for his "Description of the Santiago and Valparaiso Railway, Chilé, South America; with remarks upon resistances from curves on railways, and upon coal-burning locomotives."

*4. A Telford Premium, in Books, to William Parkes, M. Inst. C.E., for his "Description of Lighthouses lately erected in the Red Sea."

5. A Telford Medal, to M. Pernolet (of Paris), for his Paper "On the Means of utilizing the products of the Distillation of Coal, so as to reduce the price of Coke; with descriptions of the Ovens, and of the best processes in use in Great Britain and on the Continent."

6. A Watt Medal, and a Telford Premium, in Books, to Thomas Sopwith, Junior, Assoc. Inst. C.E., for his Paper "On the Actual State of the Works on the Mont Cenis Tunnel, Victor Emmanuel Railway, and Description of the Machinery employed."

*7. A Watt Medal, to William Bridges Adams, for his Paper "On the Impedimental Friction between Wheel Tires and Rails, with plans for Improvement."

8. A Watt Medal, to James Cross, for his Paper, "On the Structure of Locomotive Engines for ascending Steep Inclines, especially when in conjunction with Sharp Curves on Railways."

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* Have previously received Telford Medals.

*9. A Telford Premium, in Books, to John Mortimer Heppel, M. Inst. C.E., for his Paper, "On the Closing of Reclamation Banks."

10. A Telford Premium, in Books, to George Rowdon Burnell, F.G.S., for his Paper, "On the Machinery employed in sinking Artesian Wells on the Continent."

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* Has previously received a Telford Medal.

SUBJECTS FOR PREMIUMS.

Session 1864-65.

The Council of the Institution of Civil Engineers invite communications on the Subjects comprised in the following list, as well as upon others; such as 1° Authentic Details of the Progress of any work in Civil Engineering, as far as absolutely executed (Smeaton's Account of the Edystone Lighthouse may be taken as an example); 2° Descriptions of Engines and Machines of various kinds; or 3° Practical Essays on Subjects connected with Engineering, as, for instance, Metallurgy. For approved Original Communications, the Council will be prepared to award the Premiums arising out of special funds devoted for the purpose.

1. On the Decay of Materials in Tropical Climates, and the methods employed for arresting and preventing it.
2. On the Theory and details of Construction of Metal and Timber Arches, and of Wrought Iron Girder Bridges.
3. On Land-slips, with the best means of preventing, or arresting them, with examples.
4. On the Results of Contrivances for facilitating the Driving of Tunnels, or Drifts in Rock.
5. On the Principles to be observed in Laying-out lines of Railway through mountainous countries, with examples of their application in the Alps, the Pyrenees, the Indian Ghauts, the Rocky Mountains of America, and similar cases.
6. On the best means of preserving Railways in Alpine countries from interruptions from snow.
7. On the Principles to be observed in the designing and arrangement of Terminal and other Railway Stations, Repairing Shops, Engine-sheds, &c., with reference to the traffic and the rolling stock.
8. On Railway Ferries, or the Transmission of Railway Trains entire across Rivers, Estuaries, &c.
9. On Locomotive Engines for ascending Steep Inclines, especially when in combination with sharp curves, on Railways.
10. On the Working of Railways, with frequent Stations.
11. On the Results of the Application of Giffard's Injector to the Boilers of Locomotive and other Engines.

12. On the Working Expenses of Railways, and the influence on these of the original design and construction.
13. On the Pneumatic System for the conveyance of Passengers and Goods.
14. On the Results of a series of observations on the Flow of Water from the Ground, in any large district; with accurately-recorded Rain-Gauge Registries, in the same locality, for a period of not less than twelve months.
15. On the Construction of Catchwater Reservoirs in Mountain Districts, for the supply of Towns, or for Manufacturing purposes.
16. Accounts of existing Waterworks; including the source of Supply, a description of the different modes of collecting and filtering, the distribution throughout the streets of Towns, and the general practical results.
17. On the Structural Details, and the Results in Use, of Apparatus for the Filtration of large volumes of water.
18. On the Drainage and Sewerage of large Towns; exemplified by accounts of the systems at present pursued, with regard to the level and position of the outfall, the form, dimensions and material of the sewers, the prevention of emanations from them, the arrangements for connecting the house drains with the public sewers, the best means of limiting the contamination of rivers from the sewage discharged into them, and the disposal of the sewage, whether in a liquid form, as irrigation, or in a solid form, after deodorisation.
19. On the most suitable Materials for, and the best mode of Formation of, the Surfaces of the Streets of large Towns.
20. On the Construction of Gas Works, the most economical system of distribution of the Gas, and the best modes of Illumination in Streets and Buildings.
21. A History of any Fresh Water Channel, Tidal River, or Estuary,—accompanied by plans and longitudinal and cross sections of the same, at various periods, showing the alterations in its condition,—including notices of any works which may have been executed upon it, and of the effects of the works; particularly of the relative value of Tidal and Fresh Water, of the effect of Enclosures from the Tidal Area upon the general regime, of Sluicing where applied to the improvement of the entrance or the removal of a Bar, and of Groynes, or Parallel Training Walls. Also, of Dredging, with a description of the Machinery employed, and the cost of raising and depositing the material.
22. On the Results of a Series of Observations, illustrative of the modifications which the tidal wave undergoes in its passage up and down a river, or estuary.

23. On the Construction of Tidal or other Dams, in a constant, or variable depth of water; and on the use of wrought iron in their construction.
24. A History of any Harbour, or Dock, including the reasons for selecting the site, the mode of construction adopted, and the subsidiary works for the convenience of shipping, and for commercial purposes; with the cost, &c.
25. On Graving Docks and mechanical arrangements having a similar object, with the conditions determining their relative applicability in particular cases, as dependent on the rise of tide, the depth of water, and other circumstances.
26. On the arrangement and Construction of Floating Landing-Stages, for passenger and other traffic, with existing examples.
27. On the different systems of Swing, Lifting, and other opening Bridges, with existing examples.
28. On the Construction of Lighthouses; their Machinery and Lighting Apparatus; with notices of the Methods in use for distinguishing the different Lights.
29. On the Measure of Resistance to Steam Vessels at high Velocities.
30. On the results of the use of Tubular Boilers, and of Steam at an increased pressure, with, or without superheating, for Marine Engines, noticing particularly the difference in weight and in speed, in proportion to the Horse Power and the Tonnage.
31. On the results of the Employment of Steam Power on Canals, and of other measures for the Improvement of Canals as a means of conveyance for heavy traffic.
32. On the relative advantages of the Principle of Expansion, as applied in the Single long-stroke Cylinder Engine, in the Double Cylinder Engine, and in the Three Cylinder Engine; and on the adaptation of the two latter to marine purposes.
33. On the Principles and Varieties of Construction of Blast Engines, with British and Foreign examples.
34. On the construction of, and the comparative duty performed by, modern Pumping Engines for raising Water, for the supply of Towns, or for the Drainage of Mines; noticing in the latter case, the depth and length of the underground workings, the height of the surface above the sea, the geological formation, the contiguity of streams, &c.
35. On Turbines and other Water Motors of a similar character; and their construction and performance, in comparison with Water-wheels.

36. On the present systems of Smelting Iron Ores, and on the Conversion of Cast Iron into the malleable state, and of the Manufacture of Iron generally, comprising the distribution and management of Iron-works.
37. On the Manufacture of Iron for Rails and Wheel Tires, having special reference to the increased capability of resisting lamination and abrasion; and accounts of the Machinery required for rolling heavy Rails, Shafts, and Bars of Iron of large sectional area.
38. On the Bessemer and other processes of Steel-making; on the present state of the Steel Manufacture on the Continent of Europe; and on the employment of castings in Steel for Railway Wheels and other objects.
39. On the Use of Steel for the Tires and Cranked Axles of Locomotive Engines, especially with reference to its durability and the cost of repairs, as compared with Iron of acknowledged good quality; and on the use of Steel Bars and Plates generally in Engine-work and Machinery, for Boilers and for Shipbuilding, as well as for Bridges.
40. On the safe working strength of Iron and Steel, including the results of experiments on the Elastic Limit of long bars of Iron, and on the rate of decay by rusting, &c., and under prolonged strains.
41. On the Transmission of Electrical Signals through Submarine Cables.
42. On the present relative position of English and Continental Engineering Manufactories, especially with reference to their comparative positions in respect of the cost and the character of the work produced.
43. Memoirs and accounts of the Works and Inventions of any of the following Engineers:—Sir Hugh Middleton, Arthur Woolf, Jonathan Hornblower, Richard Trevithick, William Murdoch (of Soho), Alexander Nimmo, and John Rennie.

Original Papers, Reports, or Designs, of these, or other eminent individuals, are particularly valuable for the Library of the Institution.

The competition for Premiums is not confined to Members, or Associates of the Institution, but is equally open to all persons, whether Natives, or Foreigners.

The Council will not consider themselves bound to award any Premium, should the communication not be of adequate merit, but they will award more than one Premium, should there be several communications on the same subject deserving this mark of distinction.

The communications must be forwarded, on or before the 1st of February, 1865, to the house of the Institution, No. 25, Great George Street, Westminster, S.W., where copies of this Paper, and any further information, may be obtained.

CHARLES MANBY, *Honorary Secretary.*
JAMES FORREST, *Secretary.*

25, *Great George Street, Westminster, S.W.,*
October, 1864.

NOTICE.

It has frequently occurred, that in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors may have advanced somewhat doubtful theories, or may have arrived at conclusions at variance with received opinions. The Council would, therefore, emphatically repeat, that the Institution must not, as a body, be considered responsible for the facts and opinions advanced in the Papers, or in the consequent Discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the discussion and the inquiry; but that such notice, or award, must not be considered as any expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

EXTRACTS FROM THE MINUTES OF COUNCIL, FEB. 23rd, 1835.

"The principal subjects for which Premiums will be given are:—

"1st. Descriptions, accompanied by Plans and explanatory Drawings, of any work in Civil Engineering, as far as absolutely executed; and which shall contain authentic details of the progress of the Work. (Smeaton's Account of the Edystone Lighthouse may be taken as an example.)

"2ndly. Models, or Drawings, with descriptions of useful Engines and Machines; Plans of Harbours, Bridges, Roads, Rivers, Canals, Mines, &c.; Surveys and Sections of Districts of Country.

"3rdly. Practical Essays on subjects connected with Civil Engineering, such as Geology, Mineralogy, Chemistry, Physics, Mechanic Arts, Statistics, Agriculture, &c.; together with Models, Drawings, or Descriptions of any new and useful Apparatus, or Instruments applicable to the purposes of Engineering or Surveying."

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"Every Paper, Map, Plan, Drawing, or Model presented to the Institution, shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary, and the Council may publish the same, in any way and at any time they may think proper. But should the Council refuse, or delay the publication of such Paper, beyond a reasonable time, the Author thereof shall have a right to copy the same, and to publish it as he may think fit, having previously given notice, in writing, to the Secretary of his intention. No person shall publish, or give his consent for the publication of any communication presented and belonging to the Institution, without the previous consent of the Council."

Instructions for preparing Communications.

The Communications should be written in the impersonal pronoun, and be legibly transcribed on foolscap paper, about thirteen inches by eight inches, the lines being three-quarters of an inch apart, on the one side only, leaving a margin of one inch and a half in width on the left side, in order that the sheets may be bound.

The Drawings should be on mounted paper, and with as many details as may be necessary to illustrate the subject. Enlarged Diagrams, to such a scale that they may be clearly visible, when suspended on the walls of the Theatre of the Institution, at the time of reading the communication, should be sent for the illustration of any particular portions.

Papers which have been read at the Meetings of other Scientific Societies, or have been published in any form, cannot be read at a Meeting of the Institution, nor be admitted to competition for the Premiums.

ORIGINAL COMMUNICATIONS,

DRAWINGS, PRESENTS, &c.,

RECEIVED BETWEEN JULY 1, 1863, AND JUNE 30, 1864.

ORIGINAL COMMUNICATIONS.

AUTHORS.

Adams, W. B. No. 1,117.—On the Impedimental Friction between Wheel Tires and Rails; with Plans for Improvement. With a series of diagrams.

Bayliss, B. No. 1,110.—On the Conversion of Cast Iron into a Malleable State.

Birckel, J. J. No. 1,109.—On the Relative Position of English and Continental Engineering Manufactories.

Burnell, G. R. No. 1,120.—On the Machinery employed in sinking Artesian Wells on the Continent. With a series of diagrams.

Clark, E. H. No. 1,107.—Description of the Great Grimsby (Royal) Docks; with a detailed account of the Enclosed Land, Entrance Locks, Dock Walls, &c. With a series of drawings.

Colthurst, J. No. 1,124.—Experiments in a Running Stream on the Resistance of Floating Bodies.

Cross, J. No. 1,113.—On the Structure of Locomotive Engines for ascending Steep Inclines, especially when in conjunction with Sharp Curves on Railways. With a lithograph.

Hawthorn, T. No. 1,121.—Account of the Docks and Warehouses at Marseilles. With ten drawings.

Heppel, J. M. No. 1,097.—On the Closing of Reclamation Banks. With three diagrams.

Johnston, E. No. 1,123.—The Chey-Air Bridge, Madras Railway. With four diagrams.

Lloyd, W. No. 1,116.—Description of the Santiago and Valparaiso Railway, Chile, South America; with remarks upon Resistances from Curves on Railways, and upon Coal-burning Locomotives. With a series of drawings and photographs.

Mann, G. O. No. 1,122.—On the Decay of Materials in Tropical Climates, and the Methods employed for Arresting and Preventing it.

AUTHORS.

Meikle, W. No. 1,108.—On the Burning of Coal in the Furnaces of Locomotive Engines.

Mills, W. H. No. 1,114.—The Craigellachie Viaduct. With three drawings.

Parkes, W. No. 1,096.—Description of Lighthouses lately erected in the Red Sea. With a series of diagrams.

Pernolet, M. (of Paris). No. 1,112.—On the Means of Utilizing the Products of the Distillation of Coal, so as to reduce the price of Coke; with Descriptions of the Ovens, and of the best Processes in use in Great Britain and on the Continent, in the Manufacture of Coke. With one drawing.

Phipps, G. H. No. 1,105.—On the Resistances to Bodies passing through Water. With a series of diagrams.

Redman, J. B. No. 1,103.—The East Coast between the Thames and the Wash Estuaries. With a series of diagrams.

Sheilds, F. W. No. 1,099.—On the Embankment of the Thames at London.

Sopwith, T., Jun. No. 1,106.—The Actual State of the Works on the Mont Cenis Tunnel, Victor Emmanuel Railway; and Description of the Machinery employed. With a series of diagrams.

Taylor, J. No. 1,115.—The River Tees, and the Works upon it connected with the Navigation. With a series of diagrams.

White, C. F. No. 1,098.—Indian Woods.

Wilson, W. No. 1,119.—Account of the Water Works at Victoria, Hong-Kong.

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MAPS, CHARTS, &c.

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OFFICERS.—1864-65.

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January 10 and 17, 1865.

JOHN FOWLER, Vice-President,
in the Chair.

The discussion upon the Paper, No. 1,115, "On the River Tees," occupied both evenings, to the exclusion of any other subject.

The following Candidates were balloted for and duly elected on January 10:—Beresford Anderson, Robert Maitland Brereton, John Law Hunter, and James Adair M'Connochie, as Members; William Alexander Adams, Alexander Brogden, Henry Garland Matthews, Benjamin Oliveira, F.R.S., Colonel Saïd Bey, and Captain Jackson Muspratt Williams, as Associates.

January 24, 1865.

JOHN FOWLER, Vice-President,
in the Chair.

No. 1,121.—"Account of the Docks and Warehouses at Marseilles."[1] By Thomas Hawthorn.

In this Paper the Author proposes to give a sketch of the docks and the adjoining warehouses, the latter being remarkable on account of their completeness and extent in one mass, as well as their external appearance. He will include the particulars of some experiments he made in conjunction with M. Barret, the Engineer-in-chief, on the Hydraulic Machinery.

The port of Marseilles comprises five docks in actual use, and one in course of construction. (Plate 8, Fig. 1.) The old dock, or old port as it is generally termed, is said to have been constructed at or about the time of Louis XV. It was formed out of an inlet of the sea, and is 1,100 yards in length, with a mean breadth of 350 yards, and has often contained as many as eight hundred vessels of all sizes. Near the entrance the depth of water is from 21 feet to 22 feet; but as the drainage of a great part of the town is allowed to run into the dock, mud constantly accumulates at the upper end, which has to be removed by dredging. The same inconvenience is being experienced in the new docks, as all the drains do not discharge directly into the sea.

Adjoining the old port there is a small basin, for careening vessels,

[1] The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

and capable of containing about a dozen at one time. Near the entrance there is also a floating dock, constructed about twenty-two years ago, and belonging to the Dock Company, the works of which will be hereafter described. There are likewise two graving-docks, formed out of a canal originally used as a means of communication between the old and the new ports; but when the new graving-docks are completed, it is intended to re-open the canal for navigation.

The dock of La Joliette, the first-constructed basin of the new port, was formed by making a breakwater parallel to the shore, at a distance of about 380 mètres. It is composed mostly of artificial blocks of stone and cement, similar to those used in the construction of the docks Arenc, Lazaret, and Napoléon. The Joliette is 500 mètres long, by 380 mètres wide, and is capable of affording accommodation for about two hundred large ships, such as the steam-vessels belonging to the Messageries Impériales. This dock was constructed by the State in 1847. The Napoléon dock is 380 mètres in length by 300 mètres in width, and has just been completed by the State. The Government are also engaged in the construction of the Dock Impériale, besides repairing basins, which will be completed to the level of the quays by the Ponts et Chaussées, and be then made over to the Dock Company, on terms which will be subsequently referred to.

That part of the port of Marseilles which belongs to the Dock Company comprises the docks Lazaret and Arenc, with the adjoining quays, land, warehouses, and moles (Plate 8, Fig. 2). On the 18th June, 1854, an Imperial decree made the following concessions to the town of Marseilles:—"The establishing and carrying out, for ninety-nine years, of bonded and free docks and warehouses on that allotment of land shown by Plate 8, Fig. 2, subject to the conditions given in a 'cahier des charges.'" Article 3 of the 'cahier des charges' states, that the works to be executed by the Concessionaires are the quays, piers, moles, &c., as well as the sheds, magazines, &c., shown in Plate 8, Fig. 2; that the magazines shall be separated, one from another, by courts, or yards, partially covered, and that these courts must be sufficiently large to contain a line of railway, an ordinary road, and space for carts and merchandize; that offices, lodges, &c., should be constructed according to the demands made by the Custom-house authorities; that the Customs' dock should be isolated by a wall 4 mètres in height; that there should be lines of railway, to connect the warehouses with each other, with the quays, and with the Paris, Lyons, and Mediterranean Railway; also that an adequate stock of machines, cranes, locomotives, wagons, &c., should be provided for the efficient carrying out of the work. Article 5 prohibits the use of wood in any of the warehouses, sheds, &c.

Article 10 states that the first basin, or Dock du Lazaret, shall serve exclusively as a Customs' dock; that ships with inland goods must load and unload along the quays of the Dock d'Arenc, the quays of the breakwater, the north quay of La Joliette, or the south quay of the Napoléon Dock. Article 13 adds, that the warehouses of the bonded dock must be capable of containing at least 150,000 tons of merchandize, but limited at first to 75,000 tons, and until such time as the increasing commerce of Marseilles may demand further accommodation. The 'cahier des charges' contains thirty-nine articles, which, with the exception of those just quoted, refer mostly to the commercial administration of the docks. Article 1 enabled the town to re-grant these concessions, subject to the same 'cahier des charges,' and with the approbation of the Ministre du Commerce et des Travaux Publiques. Thus, on the 5th November, 1856, a convention was made between the mayor of Marseilles and Monsieur Talabot, representing the Dock Company, stipulating for the re-concession to the present Dock Company, on the payment annually to the town, for the first thirty years, of 50,000 francs, and during the remainder of the concession of 100,000 francs. The present capital of the company is 40,000,000 francs.

The basins Lazaret and Arenc, like the Joliette, were formed by constructing moles in the sea (the dotted lines in Plate 8, Fig. 1, show the original shore), and by forming a pier, or breakwater, parallel to the shore, for protecting the docks from the action of the sea. The earthwork for the moles of the Joliette and Lazaret, as well as all the space upon which the magazines, warehouses, &c., are built, outside the dotted lines, was taken, for the most part, from a hill immediately to the east of the docks. This hill, of nearly 100 feet in height, may be said to have been literally thrown into the sea; the number of cubic mètres of 'déblais' thus employed amounting to nearly two millions, part being used for the docks and part for filling-in to the eastward of the docks. The mole Arenc was formed with 'déblais' from the Rue Impériale, a new street cut through the old town to the level of the new town, which involved the excavation of 1,200,000 cubic mètres, (1 cubic mètre = 35·2 cubic feet.) The total amount of 'remblais' in the present grant is 1,500,000 cubic mètres, the town having furnished 513,000 cubic mètres, according to agreement. Previous to the filling-in of the Lazaret, excavations to the depth of from 8 to 10 mètres were made in some places, to remove a mass of slimy earth, formed from the residue of old soap-works, which for many years had accumulated at that part. In several places this earth was so impregnated with a green-coloured residue, that during the excavations noxious gases were given off, producing illness among the labourers engaged.

In the construction of the breakwater forming the Joliette, Lazaret, Arenc, and Napoléon Docks (Plate 8, Fig. 3), an embankment, or hearting, was first formed, of blocks of natural stone (pierre froide), levelled at a height of 2 mètres (6′ 7″) above low water.[1] At this level the surface has a width of 7 mètres, the slopes being at an inclination of $1\frac{1}{3}$ base to 1 in height. At the depth of 8 mètres below low water, the embankment is enlarged to 7·34 mètres, horizontally towards the sea, in order to receive the larger blocks of concrete, placed on it promiscuously, to break the action of the sea against the pier. The artificial blocks have a width of 10 mètres, measured horizontally at the level of low water, and they attain a mean height above low water of 3·80 mètres. The inside of the pier is constructed with natural blocks, so as to form a quay 30 mètres wide, with a wall in front, the latter having its foundations 6 mètres below the water-line. The embankment is also prolonged, forming a slope towards the dock of 2 base to 1 in height. As the formation of the embankment progressed, it was from time to time solidified, by placing on it artificial blocks in tiers, one above the other, by means of a floating crane, or derrick. The blocks generally settled down in about three months. The blocks of natural hard calcareous stone, mostly taken in barges from the islands opposite to the port of Marseilles, were arranged in different classes as follows:—

Rubble stones from 20 lbs. to 250 lbs. each; first class, 250 lbs. to 1 ton 2 cwt. each; second ditto, 1 ton 2 cwt. to 3 tons 15 cwt. each; third ditto, 3 tons 15 cwt. and upwards. It having been ascertained, by experiment, that blocks weighing 20 tons each, and measuring 10 cubic mètres each, could not be moved by the most violent sea in the Mediterranean, artificial blocks of concrete were made, of an average weight of 23 tons. The dimensions of these blocks were 3·40 mètres long, by 2 mètres wide, and 1·50 mètre deep, presenting a solidity of 10 cubic mètres. The manner in which these several classes were arranged is shown in Plate 8, Fig. 3.

In the formation of the artificial blocks, the concrete consists of two parts of hard limestone, and one part of cement; the cement being composed of five parts of sand to one of lime. The broken stones and the cement are mixed in the above proportions in portable iron cylinders, made to rotate by means of a belt, connected at pleasure with a steam-engine. The engine is also used to drive stones for mixing the cement. After the concrete has been well worked, the mixture in the cylinders is emptied into wooden moulds, the interior dimensions of which correspond with

[1] The level of the Mediterranean varies at Marseilles about 18 inches, according to wind and other influences.

the size of the blocks; and the moulds can be taken to pieces, in order to detach them from the blocks. The moulds are also so constructed, as to leave a groove around each end of the block, to admit of a chain being easily passed round, for facilitating the lifting and placing of them. The contents of each cylinder are beaten down in the moulds by two men, and this operation ought in all cases to occupy half a day for each block. The moulds are then allowed to remain at least three days, when the cases are taken off, but the blocks are not considered to have attained sufficient solidity and hardness before the lapse of three months for those that are to be thrown promiscuously into the sea to act as a breakwater, and of six months for those forming the foundations for the piers and quays. The plant necessary for the manufacture of a mean of 300 blocks per month is as follows:—

One 10-horse engine; two lime wagons, containing 6 cwt, each; four sand ditto, 2′ 6″ cube; four cement ditto; three cement mills; twelve stone wagons; four wrought-iron cylindrical concrete wagons; one hundred wooden moulds; besides iron rails and sleepers necessary for the transit of the wagons between the mills and the moulds. The blocks attain, in course of time, a hardness almost equal to that of stone. Those first put down, about sixteen years ago, are very little worn by the action of the waves. The cost of these blocks is 12*s.* 8*d.* per cubic mètre, or including the setting and other incidental expenses, 15*s.* 10*d.* per cubic mètre. The entire cost of the breakwater is from £290 to £310 per lineal mètre.

In the construction of the quay walls of the docks Lazaret, Arene, and Napoléon, the system of building on artificial blocks, somewhat similar to the inside of the pier, is adopted (Plate 8, Fig. 4). At 6 mètres below the low water level, an embankment is formed of second and third-class stones, having a base of from 8 mètres to 9 mètres, and an inclination at the sides of 1 to 2. Upon this embankment, and up to the water level, four rows of artificial blocks are placed longitudinally, side by side, making a total height of 6 mètres, each block being 1·50 mètre high, with a base on the top of 3·40 mètres wide. Two rows of blocks are usually placed on these, to settle the embankment underneath, and are allowed to remain for about six months, when these blocks are removed, a masonry wall being built up in their place to the level of the quay. At the back of this wall there are other artificial blocks, from the upper side of which a further embankment of stones is formed, having an inclination of 1 to 2. The inner space is ballasted up to the level of the quays. The height of the level of the quays in the Arene and Napoléon Docks is 2·40 mètres above the level of the water, whereas in the Lazaret Dock the height is 3·40 mètres. The

latter is so raised to serve as a platform, for the loading and unloading of railway wagons and carts. In several places the embankment beneath the artificial blocks has moved, generally slipping forward, and causing the artificial blocks, as well as the quay walls resting on them, to incline over into the dock. This has arisen, in most cases, from an insufficient time having been allowed for settling, and is generally to be observed in the quays on the moles, where in some places it has caused the walls to split. The only remedy appears to be, to allow the settling to go on as long as possible, and then to rebuild the wall, from the edge of the water, or the top of the blocks.

Plate 8, Fig. 4, shows the permanent quay fenders, and the manner of fixing them to the walls, as well as the mooring rings, the exposed parts of which are galvanized. The inner holdfasts are secured by a long bar of iron, running parallel to the quays, and let into the masonry. On account of the instability of the quay walls, as well as from the nature of the earthwork behind them, the hydraulic quay cranes have no foundations let into the masonry and earthwork as in England, but rest simply on platforms of heavy timbers. These platforms have sufficient base to insure stability during the sluing of the jibs; but as it has been found impossible to extend these platforms towards the dock, the hinder part of the crane-house is counter-weighted, with pigs of cast-iron, 3-tons being used for 3-ton cranes, and 1 ton for 1-ton cranes. This method answers very well, as the quay cranes may be levelled at any time with little trouble, by means of screw-jacks, should the quays beneath them move. It is important that the crane-houses should retain a perfectly perpendicular position, otherwise during the sluing of the jib the weight suspended does not move in a horizontal plane.

Towards the end of the Mole du Lazaret, the slipping of the quays has caused one or two party walls, as well as a gable end of a quay shed, to split. These walls will soon have to be taken down and rebuilt. The entire length of the quays, at present constructed, belonging to the Dock Company, is 2,840 mètres. The cost per lineal mètre of the quays above the embankment, that is, of the quay walls with the artificial blocks supporting them, is £24.

The space surrounding the Dock du Lazaret (Plate 8, Fig. 2) is reserved for the storing and movement of bonded goods, one entrance only being permitted, and that guarded by Custom-house officers. The warehouses within these limits are at present of one story only. The amount of covered space, including the floors, is 67,132 square mètres. These warehouses are constructed of rubble masonry, with dressed piers and quoins, and wrought-iron roofing, with vaulting in brickwork, similar to that which will be described

in the case of the large warehouses. Sheds, of 14 metres and of 10 metres in width, extend completely round the dock. These sheds are covered with a simple wrought-iron roofing of double T iron. Iron beams of an Λ section are placed transversely on the girders, for supporting the tiles. This section of iron is a French patent, and makes a light and strong roofing. This shed roofing is supported on hollow cast-iron columns, of square section. The double T girders of the roofing are allowed to slide on the top of the columns, to admit of expansion and contraction. The inner sides of the sheds are supported by stone walls, where those of the warehouses do not serve for that purpose. The front, towards the quays, is closed by sliding, or rolling doors, of corrugated zinc.

The flooring for all the warehouses and sheds consists of a layer of asphalte, half an inch in thickness, costing 2 francs per square mètre; but including the levelling of the ground, and the bed of cement below, the cost is about 6 francs per square mètre.

Parallel to the quays, and to the warehouses where necessary, tunnels, for the conveyance of the hydraulic and other pipes, are constructed at a level of 3 feet below the surface to the top of the tunnel, the latter having sufficient height for the passage of workmen in case of leakage, &c. In English docks, on the contrary, the hydraulic pipes are, for the most part, simply imbedded a short distance into the ground. These works have cost about £4 per mètre, and in all nearly £12,000.

There are also similar sheds and buildings on the quay to the south of the Dock d'Arenc, but the warehouses are not yet quite completed. These will have two vaulted floors, supported on cast-iron columns, and wrought-iron double T girders. The eastern quay, or that towards the land, is entirely occupied by goods' wagons from the railway; a line of rails passing underneath the quay cranes, where the wagons are discharged directly into the ships, and *vice versâ*. This system is about to be adopted on the Mole d' Arenc, with the exception that galleries will extend from the quay cranes to the warehouses at the level of the first floor of the buildings, so that these cranes may load either directly from the warehouses, or from the railway. The dotted lines show the position of the warehouses now being commenced.

The bonded warehouses, or 'Entrepôt Commercial,' form one block, to which are adjoined the company's offices, the latter facing to the south, while the warehouses face the west, or the Dock du Lazaret, being separated from the enclosure of this dock by two lines of railway, and the public thoroughfare which runs parallel to it. Behind, to the east side, are lines of railway for sidings from the Paris, Lyons, and Mediterranean Railway, a junction with this railway having been made by means of an incline and

tunnel under the town. The boundary line, however, of the docks is the edge of the platform of the warehouse, the lines of rail to the east belonging to the Railway Company.

The total length of these warehouses is 365 mètres (1,200 feet), with a breadth of 37·50 mètres, and a height of 35·70 mètres. The offices are of the same breadth, with a length of 37·60 mètres. (Plate 8, Fig. 2.) The warehouses[1] are in four equal divisions, exactly resembling each other. Each division contains an interior court with two doorways (Plate 9, Figs. 1 to 5), one for the entrance and the other for the departure of carts. These divisions, being four in number, are termed quarters, and are distinguished as the 1st, the 2nd, the 3rd, or the 4th quarter. Two of these quarters are now used for bonded goods, while the other two are employed for merchandise of all other descriptions. The level of the first floor is 1 mètre above the paving of the courts —that is, of the general level of the dock property, which is 2·40 mètres above the level of the sea. These warehouses have six stories above the ground floor, and vaults below, the whole being constructed in stone and iron, according to a contract which stipulates that no inflammable material shall be used in any of the buildings on the Dock property. The foundations of this building rest entirely on a bed of rock, in some places as much as 6 mètres below the level of the sea. These excavations were made at an enormous cost, as at this part, above the rock, the earth was infected with a residue from the soap factories before alluded to. The whole is constructed in irregular cut stone, or a better class of rubble masonry, with the exception of the piers, arches, quoins, ornamental work, &c., which is in cut and dressed hard limestone of good quality, and the windows, which are in dressed stone, but of a much softer quality of limestone, of a yellowish colour, and a spongy appearance, though becoming hard on exposure to the atmosphere. This stone was obtained from Miramas, in the neighbourhood of Marseilles, and was easily worked, being simply scappled. The hard stone was dressed with a sort of pick, the mason's mallet being almost unknown in Marseilles. The different kinds of masonry and brickwork used in these constructions were procured, worked, and built into place at the following prices, including transit and other expenses:—

Hard limestone, £4 per cubic mètre; less hard quality (Calissane), £3. 4*s.* ditto; soft calcareous stone (Miramas), £2. 2*s.* ditto; rubble masonry, 12*s.* 6*d.* ditto; brickwork (solid or hollow bricks), £2. 8*s.* ditto. The thickness of the walls is

[1] This block of buildings is termed 'Entrepôt Commercial,' or commercial warehouses; while the lesser, of one and two floors, for the sake of distinction, are termed 'Magazins.'

1·25 mètre at the foundations, 1·08 mètre at the ground floor, diminishing gradually at each story, the thickness at the sixth story being 0·58 mètre. The ground floor is supported by massive stone pillars and vaulting, the other floors resting on cast-iron columns. A gangway is left at each side of the court, forming a platform for the loading and unloading of carts. Two trapdoors in this platform communicate with the cellars below, goods being taken out and in by means of hydraulic traversing cranes. The communication for goods with the different floors is made by the usual system of hydraulic hoists, as in England, each quarter having two such apparatus, lifting 1½ ton each. There are also, in each quarter, two sets of lowering apparatus, the cradle going up empty, by means of a counterweight, while the extra charge brings it down again. It is completely under the control of the warehousemen, by means of a break, and may work from any floor to the ground, or between any two floors. At the entrance of each quarter, suitable apartments are provided for watchmen and porters; also rooms for the examination of specimens of goods, this being often necessitated by the Custom-house officers, who will not at all times open the magazines.

All these warehouses were constructed without the aid of scaffolding. The stonework, cement, and other materials were raised by means of three travelling cranes,—two on one side of the building, and one on the other,—running on rails parallel to the building on each side. These cranes consisted simply of a long jib, suspended a little below its centre. As soon as the load was raised sufficiently high, the top end of the jib was allowed to incline over towards the building, by means of a rope connecting the lower end of the jib with a roller worked by an engine; sufficient angularity being given to the jib, the load was lowered by means of a break on to the building. The jib then resumed a nearly perpendicular position; the empty bucket, or cradle, descending again to the ground to be recharged. The total length of the jib was 28 mètres; and the extreme load lifted was 2½ tons. This mode of construction was found to be simple and economical, each crane lifting 50 tons of material per day. All the iron work, such as the columns, girders, and roofing, was raised in the spaces in the floors left for the hoists, by means of small portable engines; the winch, boiler, and engine being all on a small frame carried upon four wheels.

The cost of the masonry of these warehouses was 3,000,000 francs (£120,000), exclusive of the foundations, the latter having cost 203,000 francs. The number of cubic mètres of masonry, independent of the foundations, was 14,136. All the doors and the window frames are of wrought iron, there being two hundred and fifty-one of the former in these warehouses, and twelve

hundred and eighty of the latter. The wrought iron for the doors weighed in all 1,600 tons, for which £30 per ton was paid, making a total for the doors of £4,800. The floors for each story are of wrought-iron double T girders of 0·500 mètre deep, resting on hollow cast-iron columns, varying in section at each story according to the load. The columns are at a distance of 4·750 mètres apart from each other throughout the whole building. Plate 9, Figs. 6, 7, and 8, gives the details of these columns and girders and their tie-rods, as well as the manner of securing the tie-rods in the walls. The junction of the two columns with the wrought-iron girders is so made as to allow for the expansion of the girders. One column simply rests on the top of the other, the two ends being turned in a lathe; while the girders rest on the lower flange of the upper column, being tied together by bolts passing through the column. The girders supporting the vaulting are tied together transversely, by wrought-iron tie-rods, at intervals of 1 mètre from each other. These tie-rods can be adjusted by a screw at one end, the other end working in a socket. The columns were all cast vertically. They are 4 mètres in height, and were tested to support a vertical load equal to 8 kilos per square millimètre of section. The wrought-iron girders were subjected to a tensional force equal to 12 kilos per square millimètre of section. An alteration of elasticity after this test was considered sufficient for the refusal of the piece.

The cost of these girders, of wrought iron, 0·500 mètre deep, weighing 145 kilos per mètre, and delivered at the docks, was £22 per ton. This apparently high price was occasioned by the extra size of iron of the I section, so large a girder not having been previously rolled. The length of each girder is 4·530 mètres. The following Table gives the weight and the cost of the wrought and cast iron used in the floors and columns.

	Number of Columns.	Weight in Tons.	Total Weight of Cast Iron.	Tons of Wrought Iron.	Cost in Francs.
Ground floor . . .	..	..	914	489	530,660
1st floor	304	494			
2nd floor	304	308	382	496	374,848
3rd floor	304	268	349	498	365,842
4th floor	304	234	550	498	366,719
5th floor	304	312	428	506	394,137
6th floor	..	..	112	499	294,386
					2,326,592

The contract price for the columns and pedestals, delivered at the docks, was 300 francs per ton; for wrought-iron girders,

0·50 mètre deep, 550 francs per ton; for other pieces of wrought iron, such as tie-rods, &c., 500 francs per ton; and for ordinary castings, 270 francs per ton. The vaulting between the girders is built of hollow bricks, 6 inches deep, costing 10 francs per square mètre complete. The space between the asphalte of the flooring and the vaulting is filled with cement. This is made perfectly level on the surface previous to the application of the layer of asphalte, which, as before stated, is half an inch in thickness, and costs 2 francs per square mètre.

The floors are constructed to carry 2 tons per square mètre throughout the whole building; but from the care taken in the selection of the materials and in the construction, they would probably carry much more with safety. The whole of this iron is the produce of French manufactories, and the work is excellent, the castings being sound, and the heavy girders carefully rolled.

The wrought-iron roofing of the warehouses, shown in detail in Plate 9, Fig. 9, is of the style generally adopted by the Dock Company for all its constructions, with the exception of the quay sheds, which are formed entirely of double T irons. Previous to the erection of these buildings, it was determined, by experiment, that a welded piece, or rod of wrought iron, in no case resisted more than 85 per cent. of the tensional strain that would be borne by a non-welded piece of the same section. It was therefore determined to have as few welds as possible throughout the dock buildings, and in the roofing, where lightness was necessary, to have none at all. Hence, all the tie-rods, &c., have simply been bent round the bolts, instead of eyes being formed. The girder (Plate 9, Fig. 9) is composed of two angle-irons at the top, and two at the bottom of the section, separated by strips of flat iron, forming a sort of lattice web, the struts being of wrought iron. The end of each girder rests on a cast-iron shoe bedded on the wall, and is simply held transversely, allowing free play in the direction of its length for expansion. The girders are 4 mètres apart from centre to centre, and are separated at the crown by girders of similar construction. The tiles are supported by galvanized irons, termed 'Fer Zorés,' running from girder to girder, at intervals of 323 millimètres. This section of iron permits of great lightness in proportion to its strength. It was some time before efficiency was arrived at in the rolling, but, by the apex being left a little thick, the manufacture was much facilitated.

The depth of the Λ section, in the case of this roof, is 8 centimètres; but these irons are now often made much larger, and are used in some cases as floor rafters. The following is a list of some of them, with the weight per mètre, and the prices in each case, galvanized and delivered at the docks.:—

	Weight per Mètre. Kilogrammes.	Cost per Cwt. £. s. d.
A 20 centimètres high . . .	38	2 16 8
15 ,, ,, . . .	20	2 13 4
10 ,, ,, . . .	10	2 10 0
8 ,, ,, . . .	6	2 8 4

They may be in lengths of from 7 mètres to 8 mètres if required. The extreme load this roofing ought to bear is 4 cwt. per square mètre. The shoe on the wall, upon which each girder rests, is secured by a single bolt for each piece. The bolt is held by another bolt or rod running transversely to it. This roofing is exceedingly pretty and light. The Author thinks there is no similar construction equal to it in England, where expense at the outset is more considered than by public companies in France. The vaulting between the girders renders this roofing perfectly water-tight, so that even goods liable to be damaged by damp may be stored in the sixth story. At present this floor is much used for grain. The vaulting is formed of hollow bricks, similar to those used for the floors, but much lighter. The corners are filled with hollow cylindrical tiles and cement, a concave space being left between the girders on the top for letting off any water that may pass between the tiles. The cost of this vaulting, including all expenses, is 6*s.* 8*d.* per square mètre. In the roofing of these warehouses there are 340 tons of cast and wrought iron, at a mean cost of £24 per ton, making a total of £8,160.

The hydraulic pressure and outlet pipes are conveyed along the outside of the building, under the railway platform, in a tunnel permitting of access in case of repairs being necessary. In the building itself, the pipes are contained in cast-iron troughs, bedded in the floors, and covered with cast-iron plates. Water pipes also from the town, with a pressure equal to 4 atmospheres, to be used in case of fire, are carried to every floor in each quarter of the building. Moreover, a tank is provided on the roof of each quarter, containing 40 tons, in the event of the town supply being cut off.

The whole of the door locks are Fichet's, and are similar to Stubb's. They are double, two keys being necessary to open them. In the bonded warehouses, one key is held by the Dock Company, while the other is in the hands of the Custom-house officers.

It is believed that these warehouses cannot be surpassed in point of construction. The general arrangements have been carefully studied, from examples in England, and then adapted to the commerce of Marseilles.

It is intended to cover over the courts of these warehouses with wrought iron and glass, as a protection from the rain. This

building has cost in all, comprising machinery, hydraulic pipes, &c., 12,500,000 francs (£500,000).

Graving Docks.

Previous to the Crimean war, the only facilities at Marseilles, for examining and repairing the hulls of ships, consisted of a floating wooden pontoon dock, and a small stone basin adjoining the old port, for careening on the usual system. About the year 1854, the 'Messageries Impèriales' having bought several large steamers in England, the necessity for immediate dock accomodation was felt. It was then decided to convert the existing canal, which formed a communication between the old and the new ports, into two dry basins, by constructing a partition wall at the centre, and by placing a caisson gate at each extremity, the water being pumped out by steam power. This work was executed by M. Pascal of the Ponts et Chausées, in 1856, and on its completion was conceded to the Dock Company. The south basin is 115 mètres in length, by 16 mètres wide, and 8 mètres deep. The north basin is 98 mètres long, by 16 mètres wide, and 8 mètres deep. Both are of rectangular section, the depth of water in each being 6·40 mètres, or capable of admitting a ship drawing 20 feet of water. The former basin contains 10,986 cubic mètres (1 cubic mètre of water = 1,000 kilos. = 1 ton.) The division wall between the ends of the basins is 4 mètres wide. The cost of the construction of these two docks, with their appurtenances, was—

	£.
Excavations, masonry, and cement work for the South Dock .	4,560
Ditto ditto ditto North Dock .	4,160
Partition wall	520
Engine-house	1,040
Sheds, office, &c.	120
Necessary keel-blocks, struts, and fenders . . .	3,200
Two caissons for the lock-gates, with framing in oak . .	11,600
Two steam pumping-engines complete	6,000
	£31,200

One of the pumping-engines is of 90 H.P., and works three of Gwynne's centrifugal pumps, for emptying the basins, and the other is of 16 H.P., for keeping the docks dry, against leakage from the gates.

The 90-horse engine is vertical, with one cylinder 0·70 mètre diameter, and a stroke of 0·60 mètre, acting directly on to a shaft carrying three large sheaves of 4·20 mètres diameter each. The mean number of revolutions per minute made by this engine is 90, while that of the pumps is 500. This engine is supplied with steam by three plain cylindrical boilers, at a pressure of 50 lbs. per

square inch. The south dock is emptied on an average in 4¼ hours, and the north dock in 3¼ hours; that is, 61 cubic mètres, or tons, are lifted a mean height of 4·50 mètres per minute. These pumps work remarkably well, but unfortunately the consumption of fuel per horse power of the water lifted is considerable—about 25 lbs. per hour, arising partly from the friction caused by the immense speed at which it is necessary to drive the pumps. The discs have a diameter of 580 millimètres, with a discharge and suction pipe of 380 millimètres diameter. The original pumps, from England, had brass discs; but it was found, owing to the galvanic action produced by the salt water, when brass and iron were combined, that they soon became loose; hence cast iron is now adopted.

The iron caissons, or gates (Pl. 9, Figs. 10 to 13), are constructed according to the old system usual in England, or nearly so. They are floated in and out of their places, by the filling and emptying of a tank on the top of each gate. The material used in the construction of each gate, with the framework let into the masonry, is 95 tons of wrought iron and 4·5 tons of oak. 18 tons of ballast are placed in each caisson. The average number of ships docked annually in these two docks, the south basin generally taking two at a time, is one hundred and sixty.

The floating dry dock, built eighteen years ago, is constructed entirely of wood. This dock is simply a box, 64 mètres in length, by 19 mètres in breadth, and 7 mètres in depth. The principal parts, such as the angles, ribs, longitudinal beams, sluices, and doors are of oak, the remainder being of Riga fir. The sections of the sides are triangular, 100 tons of stone ballast being placed within these spaces, for the purpose of sinking the dock when required. The draught of the dock, when empty, is 0·800 mètre, or equal to 966 tons. The dock is emptied by an engine of 10 H.P., having a single tubular boiler supplying steam at a pressure of 40 lbs. per square inch; the engine works four single-acting pumps, known in France as Le Testu's system, consisting simply of a conical piston with leather valve on the whole surface. These pumps empty the dock in 4½ hours. This dock cost for construction, with engines, &c., complete, 355,000 francs; at present its value is estimated at 125,000 francs, the wood having been eighteen years in the water; yet no appearance of rot can be detected, nor has the worm affected it; in fact, the latter cannot exist here on account of the residue from the soap factories. The trenails of acacia are not now to be depended upon, and the iron bolts, which have been unfortunately used instead of brass, are in some places eaten away to half their original section. The bolts number about 20,000.

One angle of the dock has, in course of time, sunk about 18 inches below its original level. This arose from faulty construc-

tion, additional strength not having been given to the dock where the engine is placed. Thus, notwithstanding that extra timbers were previously added, the water at times comes up as far as the foundation plate of the engine, especially if the ship in the dock be at all large. Ships with uneven keels are carefully excluded, on account of the danger of causing too great a strain on this old structure, should the keel blocks not have been accurately adjusted to the keel. It is, however, absolutely necessary to keep this dock in working order, until such time as further graving-docks are completed, the present accommodation not being sufficient. As soon as other docks are completed, the use of this wooden graving-dock will probably be abandoned, and the canal between the old and the new ports will also be reopened, as this communication is much demanded by the commerce of Marseilles.

The new graving-docks (Plate 8, Fig. 1) now being commenced at the northern extremity of the docks, leading out of the Dock Impériale, will comprise two dry basins, one of 130 mètres in length, and the other of 110 mètres in length, to be emptied by steam power. In addition to these two basins, there will be an hydraulic lift on Mr. Edwin Clark's system, capable of lifting a ship of 4,000 tons. A suitable shallow basin will also be made to contain the pontoons, upon which the ships will remain during repairs, painting, &c. These works will be constructed to the level of the quays by the Ponts et Chaussées, and will then be leased to the Dock Company for a period of ninety-nine years. The company will complete all the machinery, workshops, &c., belonging to this system of graving-docks, at a cost of about four million francs, and will carry out the working of the whole. The estimate for the works up to the level of the quays is nine million francs, of which three millions are to be paid by the Company.

The hydraulic machinery is precisely similar in character to that which Sir William Armstrong has so largely applied for docks in England. Only those particulars, therefore, will be given which are peculiar to these docks, viz., the extent of the machinery, the prices paid to the Société des Forges et Chantiers for its construction, and, lastly, the results of a series of experiments made with a view of ascertaining the useful mechanical effect of these machines, as compared with direct steam power, together with some particulars noticed during the working of this machinery.

The present stock of hydraulic machines in actual use comprises one 120 H.P. steam engine, with two accumulators; eight $1\frac{1}{2}$-ton hoists for the large warehouses; two $1\frac{1}{4}$-ton hoists for magazines; eight cellar cranes for the large warehouses; eleven quay cranes, having a maximum lift of 3 tons; twelve ditto of 1 ton; three warehouse cranes with a lift of $1\frac{1}{4}$ ton; three rotary three-cylinder

hydraulic engines, of 8, 10, and 16 H.P. respectively, working mills for crushing sugar.

The machines now in construction, or about to be ordered, are, one 120 H.P. steam engine, with three boilers; two accumulators; seven 1-ton quay cranes; eleven 3-ton ditto; eight lowering machines; forty-five hoists of different descriptions.

The following are the prices paid to the Société des Forges et Chantiers for the machinery now completed and in actual use. The contract was sealed in November, 1860, and it stipulates for the strict adherence to the designs furnished by Sir W. Armstrong, for the guarantee of these machines for six months after completion, and for the payment of all patent rights. For metal of all sorts, finished and fitted in place—for all engines, and hydraulic machines, such as hoists, quay cranes, cellar cranes, &c., £56 per ton; for the accumulators complete, £40 per ton; for the boilers, and all pertaining to them, £32 per ton; for all chains and iron work, independent of the actual working machinery, such as foot-plates, &c., £28 per ton; for all pieces of cast iron, independent of machinery, when the number of these pieces does not exceed five, and for the hydraulic pipes fitted in place, &c., £18 per ton, but, when the number of pieces exceeds five, £14 per ton; and for rough pipes to keep in stock, £12 per ton. For oak the price is £11, for pine £9, and for fir £7 per cubic mètre in each case.

The specifications are, of course, much more detailed, but the above will suffice to give a general idea of the cost. The Engineers of the Dock Company have the right of inspecting the machinery in course of construction, and of rejecting any piece from defect in material, or nonconformity with the drawings, from the commencement of the works until the end of the guarantee.

The general arrangements of the hydraulic engines, with their boilers and accumulators, are shown in Plate 9, Figs. 14 and 15. The second engine is now in course of construction by the Société des Forges et Chantiers, the whole being contracted for at a cost of 143,000 francs, subject to the same conditions as the former. This price is somewhat lower than the first engine, as the drawings, models, &c., of the former will serve for the second machine.

Experiments on the Hydraulic Machinery of the Docks.

The object of these experiments was, first, to find the volume of water actually given out by the hydraulic pumps, as compared with the interior volume of these pumps, or their working capacity, at different speeds of engine; and, secondly, the useful mechanical effect of the hydraulic apparatus, as compared with the engine and accumulator.

The effective quantity of water given out by the force pumps

was determined by comparing it with the working capacity of the pumps, or that liable to be filled at each stroke. Twenty revolutions of the engine, or eighty simple strokes of the pumps, served as a basis for the calculations. All communication, excepting with the accumulator, being cut off, the rise of the accumulator during these twenty revolutions of the engine revealed the exact quantity of water given by the pumps. A plank of wood being fixed to the accumulator guides, the rise was exactly determined by a man, riding on the crosshead of the ram, pressing a pencil on the plank as soon as the twenty revolutions were commenced, and withdrawing it upon their termination, leaving a line exactly corresponding to the ascent, which distance, multiplied by the section of the ram, indicated exactly the volume of water given by the pumps. Twelve consecutive observations were made, increasing gradually the speed of the engine at each observation, and noting the exact time occupied by the twenty revolutions. The pressure on the accumulator was taken by a Bourdon's pressure-gauge, as well as calculated by the weight on the ram. The pressure indicated depended upon whether the ram was ascending or descending; thus, in rising, it indicated 52½ atmospheres, and in descending, 51½ atmospheres. The difference, 1 atmosphere, is equal to double the friction, hence the friction = 757 kilogrammes. The total weight on the ram at 52 atmospheres = 78,750 kilogrammes, which divided by 757 = friction, or ·97 per cent.

The principal dimensions of the engine, force pumps, and accumulators, are—Engine: number of steam cylinders, 2; diameter of steam cylinders, 540 millimètres; stroke of pistons, 960 millemètres. Accumulators: diameter of ram, 432 millimètres; total pressure on ram, 78,750 kilogrammes. Force pumps: number of pumps, 2; diameter of pistons, 140 millimètres; diameter of rams, 98·5 millimètres; stroke, 960 millimètres; surface of pistons, 15,393 square millimètres; section of rams, 7,542 square millimètres; annular surface, being the difference of the two latter, 7,851 square millimètres; mean working capacity given by simple stroke of pump,[1] 7·389 cubic decimètres; working capacity evolved by 1 revolution of engine, 29·55 cubic decimètres; working capacity evolved by twenty revolutions of engine, or eighty simple strokes of pump, 591·13 litres (1 litre = 1 cubic decimètre).

The pumps are differential and double acting; that is, the volume of water given by the forward stroke corresponds to that given by the surface of the piston, minus the section of the ram, while that of the return stroke corresponds to the section of the ram only.

[1] By working capacity is meant, the exact vacuum space left by the piston on each side of it.—T. H.

The following Table contains the results of twelve experiments:—

TABLE No. I.

Work done by Force Pumps.

Comparison of Work given out by Engine, Pumps, and Accumulators.

Accumulators.					Force Pumps.		Engine (Steam).			
Lift or Stroke of Accumulator during 20 Revolutions of Engine, in Metres.	Duration of 20 Revolutions, in Seconds.	Volume of Water in cubic Decimetres or Litres forced into Accumulator during 20 Revolutions of Engine.	Volume of Water in Litres forced into Accumulator per Second.	Corresponding Force in Kilogrammetres.	Number of Horse Power, counting 75 Kilogrammetres per Horse Power.	Working Capacity in Pumps in 20 Revolutions of Engine.	Difference between Working Capacity evolved by Pumps in 20 Revolutions of Engine, and corresponding Volume of Water forced into Accumulator, in Litres.	Loss of Pumps per Cent., as compared with Working Capacity of Pumps.	Number of Revolutions per Minute.	Speed of Pistons per Second, in Metres.	Mean Pressure in Kilos. per square Centimètre on Pistons.	Indicated Horse Power in Steam Cylinders.	Comparison of Water accumulated, with Indicated Horse Power per Cent.
3·778	190	553·85	2·915	1,581	21	591·13	37·28	6·31	6·3	0·202	2·131	26¼	80
3·815	109	559·28	5·131	2,782	37	..	31·85	5·38	11	0·352	2·172	46½	79
3·810	90	558·55	6·206	3,366	44·8	..	32·58	5·51	13·3	0·426	2·250	58½	76·5
3·780	90	554·15	6·157	3,339	44·5	..	36·98	6·25	13·3	0·426	2·250	58½	76
3·280	85	560·01	6·558	3,573	47·6	..	31·12	5·26	14·1	0·451	2·280	63	75·5
3·815	85	559·28	6·579	5,568	47·5	..	31·85	5·38	14·1	0·451	2·280	63	75·4
3·800	70	557·08	7·958	4,316	57·5	..	34·05	5·76	17·2	0·550	2·302	77½	74·2
3·847	66	563·97	8·545	4,634	61·7	..	27·16	4·59	18·2	0·582	2·325	83½	73·9
3·870	60	567·34	9·455	5,127	68·3	..	23·79	4·02	20	0·640	2·357	92	74·2
3·875	48	568·07	11·834	6,418	85·5	..	23·06	3·90	25	0·800	2·380	116½	73·4
3·820	42	560·01	13·333	7,230	96·4	..	31·12	5·26	28·5	0·912	2·393	133	72·4
3·885	37	569·54	15·393	8,340	111·3	..	21·59	3·65	32·5	1·040	2·446	156	71·3

Note.—1 kilogrammètre = 1 kilogramme raised 1 metre in 1 second. 75 kilogrammètres = 33,000 foot-pounds = 1 horse power.

Hydraulic Hoists.

The effective, or useful, power of these machines was found by comparing the mechanical effect of the load lifted to the volume of water used, the value of which is known by the pressure indicated at the accumulator. Two experiments were made; the first with five hoists working simultaneously, each laden with 1,500 kilogrammes (1½ ton) during 1½ hour; the second with one hoist, varying the load on the cradle at each lift. In the first experiment, the number and height of the lifts made by the five hoists in 1½ hour, with 1½ ton on each cradle, were noted. This work was compared with the volume of water used, this volume being 90·03 per cent. of the working capacity of the pumps, calculated from the number of strokes of the engine during the 1½ hour.[1] To calculate the indicated horse-power of the engine, diagrams of each cylinder were taken every ¼ hour. The speed of the engine was so regulated as to maintain, as nearly as possible, the accumulator at ½ stroke, so that the volume of water used was equal to that given by the pumps. The quantity of coal consumed cannot be considered as a result, the fires being pushed, to keep the steam pressure up to 4½ atmospheres, including the external atmosphere.

Principal Dimensions of the Hoists.

Diameter of ram . . .	254 millimètres.
Section of ram	506·7 square centimètres.
Extreme length of stroke . .	3·094 mètres.
Purchase (reversed) . .	8 to 1.
Extreme lift of cradle . .	24·750 mètres.
Load	1,500 kilos. = 1½ ton.

Experiment No. 1.

Three boilers under steam, the pressure being maintained at 4·5 atmospheres (French measurement).
Engines cutting off steam at ½ stroke.
French coal (Rocher blen) consumed in 1½ hour = 760 kilos.

Number of Lifts made during Experiment by each Hoist.	Height of each Lift in Mètres.	Total Height of Lift in Mètres.	Remarks.
91	21·850	1988·3	
92	21·780	2003·8	
87	21·780	1849·9	
67	21·775	1458·9	Obliged to work slowly as sheaves heated.
92	21·775	2001·5	

[1] This is less per centage than was given in the first experiments with the force-pumps, and arises probably from a little variation in the height of the accumulator.—T. H.

CONTINUATION of EXPERIMENT.

Engine. Steam Cylinders.

Number of revolutions in 1½ hour	2,225
Number of revolutions per minute	24·772
Speed of pistons per second	0·7911 mètre.
Mean pressure on pistons per square centimètre	2·42 kilos.
Power indicated in two cylinders in kilogrammètres	8,767
Indicated horse power	116
Total consumption of coal per hour	507 kilos.
Total consumption of coal per indicated horse-power per hour	4·37 kilos.

Pumps.

Working capacity of pumps per revolution of engine	29·56 litres.
„ „ in 2,225 revolutions	65,771 litres.
„ „ per second	12·178 litres.
Working capacity given by five rams of hoists per second	10·96 litres.
Loss of pumps	10 per cent.

Hoists.

Total number of lifts made by five hoists	429
Total height of lifts in 1½ hour	9347·4 mètres.
Corresponding speed of cradle per second	1·731 mètre.
Load on cradle	1,500 kilos.
Mechanical effect resulting from load lifted in kilogrammètres (1,500 × 1·731 m.) =	2596·5
Horse-power of 75 kilogrammètres	34·62
Coal burnt per horse-power per hour	14·64
Speed of rams per second (the mean of five hoists taken as single result)	0·216 mètre.
Volume of water used per second in each hoist	10·96 litres.
Mechanical force in kilogrammètres of water used (pressure 52 atmospheres)	5885·5
Horse-power in water used	78·47
Coal consumed per horse-power of water used	6·46 kilos.

RECAPITULATION.—COMPARISONS of Indicated HORSE POWER of ENGINE, with WATER used, and LOAD lifted by HOISTS.

	Horse Power.	Power of Engines being 100.	Force contained in Water being 100.	Consumption of Fuel per Horse Power.
				Kilos.
Engine	116	..	..	4·37
Water used	78·47	67·64	100	6·40
Load lifted by hoists	34·62	20·8	44·05	14·64

EXPERIMENT No. 2.

This consisted in varying the load on the cradle of one hoist from 0 until the load was in equilibrium with the power of the machine. Bags of sand were carefully weighed, containing each 50 kilos. (1 cwt.), and the load was increased at each lift by 100 kilos. (2 cwt.). In Table No. 2 the results at every 500 kilos. only are given, this being sufficient to compare the work at different loads.

TABLE No. 2.

RESULTS of EXPERIMENTS made with one HYDRAULIC HOIST, commencing with the Cradle Empty, and then increasing the Load gradually until in Equilibrium.

Lift of cradle during experiments 24·56 mètres. Quantity of water used at each lift 155·56 litres.
Stroke of ram „ 3·07 „ Pressure of water used in accumulator 52 atmospheres.

Load lifted on Cradle in Kilos.	Mechanical Effect of Load lifted 24·56 m. in Kilogrammètres.	Pressure on Ram arising from Load on Cradle, the Machine being at rest, in Kilos. per square Centimetre.	Mean Pressure of Water in Cylinder, measured from Diagrams taken at each Lift, in Kilos. per square Centimètre.	Mean Total Pressure on Ram in Kilogrammetres.	Mechanical Work given out by Water in Cylinder during each Lift, in Kilogrammètres.[1]	Mechanical Force contained in Water used to lift Load = 155·56 litres at 52 Atmospheres, in Kilogrammètres.	Friction caused by Ram, Sheaves, Chains, Guides, Counterweights, &c., in Kilogrammètres.	Comparisons.		
								Mechanical Work of Load lifted. The Power contained in Water used at 52 Atmospheres being 1.	Mechanical Work done by Water in Cylinder. The Power contained in Water at 52 Atmospheres being 1.	Mechanical Work of Load lifted. The Work contained in Water used in Cylinder being 1.
0	..	3·50	8·00	4053·68	12444·79	83,546	12444·79	..	0·148	..
500	12,280	12·50	19·60	9931·32	30489·15	..	18209·15	0·146	0·365	0·402
1,000	24,560	20·50	29·90	15150·33	46510·52	..	21950·52	0·293	0·556	0·528
1,500	36,840	28·00	40·40	20470·68	62844·74	..	26004·74	0·440	0·752	0·586
2,000	49,120	36·00	51·00	25541·70	79334·01	..	30214·01	0·558	0·949	0·619
2,050	50,348	37·00	52·63	26667·60	81869·53	..	31521·53	0·602	0·980	0·614

N.B. Weight of cradle = 750 kilos., not noticed, being considered as part of apparatus.

[1] Total mean pressure on ram multiplied by stroke.

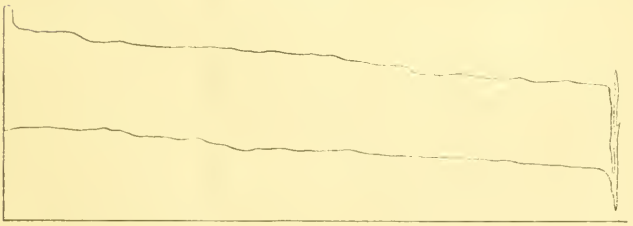
In order to ascertain the mean pressure on the ram during its stroke, an indicator, similar to that used for the steam cylinders, and constructed expressly for that purpose, being graduated up to 60 atmospheres, was placed on the hydraulic cylinder. The diagrams from this indicator were very clear, and showed exactly the work going on in the cylinder. Three of these diagrams, corresponding to Table No. 2, are given.

Cradle empty.
Mean pressure on ram = 8 kilos. per square centimètre.
Ascent, 25 sec. Descent, 23 sec.

Fig. 1.

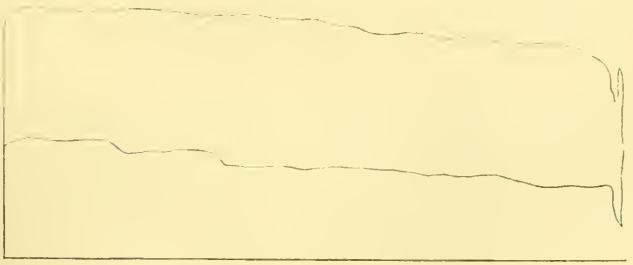
Load on Cradle, 1 ton.
Mean pressure on ram = 29·90 kilos. per square centimètre.
Ascent, 24 sec. Descent, 26 sec.

Fig. 2.



Load on Cradle, 2 tons.
Mean pressure on ram = 51 kilos. per square centimètre.
Ascent, 34 sec. Descent, 42 sec.

Fig. 3.



The lift of the cradle was always exactly 24·56 mètres, and

hence the stroke of the ram was $\frac{1}{8}$th of this, or 3·07 mètres. The quantity of water at 52 atmospheres entering the cylinder at each lift may be exactly found. By the indicator is known the exact mean pressure on the ram, diminished by the ram receding, as the water enters the cylinder; except in the case where the cradle is in equilibrium, and then the pressure on the ram is exactly equal to the pressure of the water. The exact effective work done is found by multiplying the load by the height it is raised. These taken together give the effective work done by the hoist, as compared with the water used to do that work, and by deduction, as in the preceding tables, the exact amount of friction is also found.

From these experiments it would appear, that the weight lifted by the hydraulic apparatus, on the principle described, is only about 45 per cent. of the power contained in the water, and 30 per cent. of the indicated horse-power on the steam piston. This would seem to be a small result; yet when many machines are used, there is no doubt of the great advantage of this system, only one steam engine being used, and this collecting its force by means of accumulators, for a moment when many machines may be working simultaneously. But it may be added, that these machines were perfectly new, and that the return water was always expelled back to the engine-house, a considerable distance in many cases. The length of 5-inch piping laid from the engine to the various cranes, &c., is 3,500 metres, and the same for the return-pipes (6 inches in diameter). The cistern at the engine-house is at a higher level than the machine cylinders, in order that the latter may be always full of water. The results from experiments made with a three-cylinder direct-acting rotary engine of 8 H.P., were much greater in proportion to the water used.[1] In these experiments the power was found, by attaching a sheave and break directly to the shaft, the lever of the break being 800 millimètres, the extreme weight lifted at this leverage being 182 kilos., making exactly 40 revolutions per minute. This was equal to 8·13 H. P., while that of the water used = 12·6 H.P., thus the useful mechanical effect was 65 per cent. of the water used; or 20 per cent. more than in the case of the hoists.

It will be evident that no expense whatever has been spared in any of these works. Thirty million francs have been already expended by the Dock Company under the concession of 1856, without including any part of the breakwater. To complete the works remaining to be executed under this concession, not including the

[1] This increase arises from the fact of the engine being direct acting, and hence the absence of chains and multiplying gear.—T. H.

graving docks about to be constructed, the administration has voted a further sum of forty million francs. This will include the purchase of extra land bought by the company.

Up to the present time the docks have not been a success, in a commercial point of view. The ' Portefaix,' a class of labourers peculiar to Marseilles, their forefathers having been engaged as they are, solely in the loading and unloading of ships, are divided into gangs, each gang having a leader termed ' Maitre Portefaix.' These latter have societies among themselves, and are for the present, as it were, leagued against working by machinery, considering that it will rob them of their bread. These men all work by the piece, and many, being rich, have some influence with the Marseilles merchants. Hence the quay cranes, and other machines, often remain idle, from the persistence of these men to maintain hand labour. But in a short time, these docks cannot fail to reap great profits, from the accommodation afforded by them, as well as from the fast-increasing commerce of Marseilles, the imports and exports to which may now be estimated at three millions of tons per annum.

The Paper is illustrated by a series of drawings, from which Plates 8 and 9, and woodcuts Figs. 1, 2, and 3 have been compiled.

Mr. VIGNOLES said he was at Marseilles about the year 1846, when some of these works were being commenced; and he afterwards crossed over to Algiers, where the concrete blocks were used to a large extent, and he obtained the best information he could as to their dimensions. Various statements had been made with regard to the wearing away of such blocks; and it had been asserted by some Engineers, that there was a chemical property in the water of the Mediterranean which decomposed the concrete blocks. That was said to have been the case at Algiers. The sea was heavier there than at Marseilles; and he had been informed, that blocks weighing 20 tons had been displaced by the force of the sea; but it would be interesting to ascertain, from those better acquainted with the subject, whether any large amount of disintegration of the blocks occurred.

Mr. FOWLER, V.P., remarked, that it was stated in the Paper that these blocks had been in use sixteen years, and were very little worn.

Mr. HAWKSHAW, Past-President, said, if he recollected rightly, he saw, some years since at Genoa, or Leghorn, a breakwater of concrete blocks which were old and weather-worn. The general impression appeared to be, that those blocks had been there for half a century. As he was using concrete blocks very extensively, he was anxious to know the probable duration of them. The blocks he referred to were channelled, apparently by attrition, but not more than many kinds of sandstone would have been in a similar situation. As far as his own experience went, he saw no reason to suppose that the concrete blocks were affected by the chemical action of the sea-water; and the other components being properly arranged, the duration of the blocks depended upon the stone which was used. He believed, if the cement was of proper quality, such blocks would be durable for works of this kind.

The Paper raised a question, which, it would be remembered, had been discussed at the Institution previously, viz., the cost of the various modes of forming breakwaters,[1] and the sea slope which these blocks took was an important element in such a calculation. Various slopes were put forward as those which must be taken for calculating the quantity of 'pierre perdue' to be thrown into the sea. It was obvious the slope would depend on the depth of the sea, the magnitude of the waves, and the weight of the blocks used to resist the force of the waves; and without a knowledge of all these conditions, it was impossible to determine the slope. At Holyhead, the material was simply blasted from the mountain,—stones, large and small, and sand, being used indiscriminately; at the extremity of that breakwater there was a

[1] *Vide* Minutes of Proceedings Inst. C.E., vols. xviii. and xix.

DOCKS AND WAREHOUSES AT MARSEILLES.

PROPOSED BREAKWATER

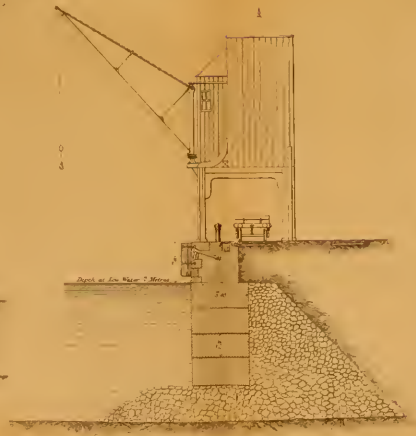
Fig 1

SKETCH OF MARSEILLES HARBOUR

Fig 3

SECTION OF MARSEILLES PEIR FORMING NAPOLEON DOCK

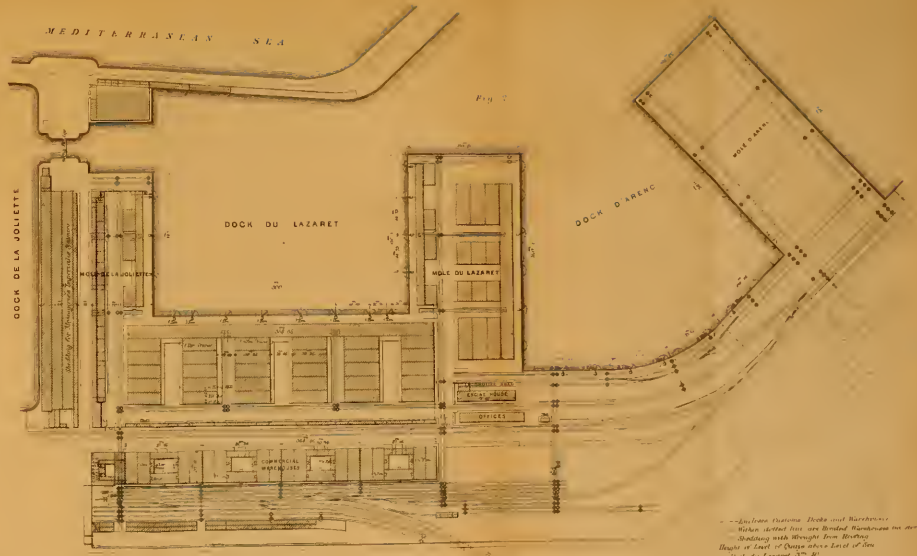
Fig 4



SECTION OF QUAYS OF DOCK D'ARENC

MEDITERRANEAN SEA

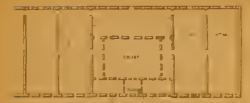
Fig 2



GENERAL PLAN OF DOCKS AND WAREHOUSES
FINISHED AND IN EXECUTION FEB 1864

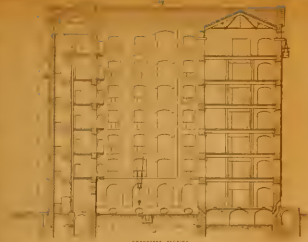
Scale 200 Feet to 1 Inch

FACADE



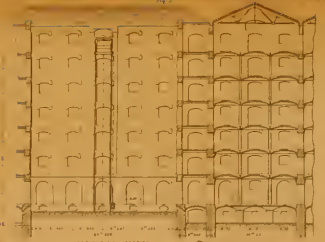
PLAN OF 2ND STORY

PLAN OF GROUND FLOOR

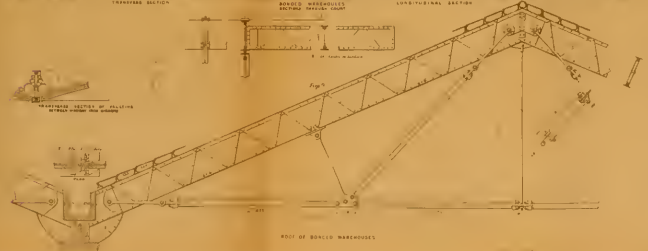


TRANSVERSE SECTION

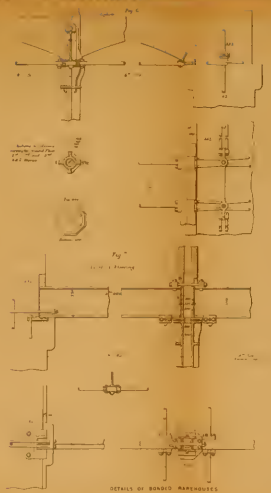
BONDED WAREHOUSES
SECTIONS THROUGH COURT



LONGITUDINAL SECTION

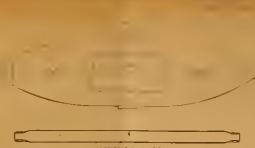


ROOF OF BONDED WAREHOUSES

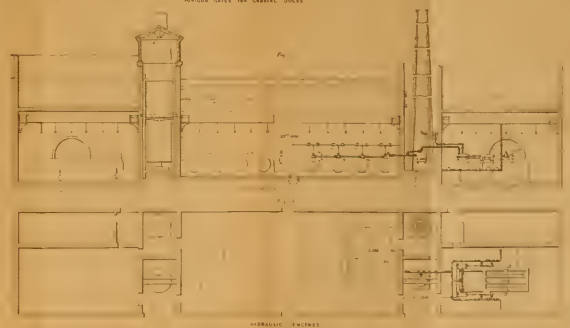


DETAILS OF BONDED WAREHOUSES

PONTOON GATES FOR CARENAC DOCKS



SECTION THROUGH A B



HYDRAULIC ENGINES

depth of 55 feet at low water, and of 75 feet at high water, which was much greater than the depth at Marseilles, where there was no rise of tide. At Holyhead the sea slope was 5 or 6 to 1; at Marseilles it was $1\frac{1}{2}$ to 1.

Mr. LEEDHAM WHITE remarked, that the chemical action of the water on the blocks of concrete had been ascribed to the magnesia contained in sea water. After frequent observations, he could not see any foundation for that belief. His own opinion, as to the degradation of the blocks, was the defectiveness of the hydraulic lime, which now obtained the hardness of granite, or of the best kinds of cement, and, after exposure to the water, gradually wore away: but not to a greater extent than probably would be the case with many kinds of stone. At Cherbourg, where Portland cement was used, the water tended to harden the material, and there was no reason to suppose that magnesia would act more injuriously on one substance than the other. The kind of cement used at Marseilles was hydraulic lime, with, he believed, a small quantity of natural cement mixed with it. It was better than the hydraulic limes in use in England, excepting the lias, but not equal to the best kinds of artificial cement made in France and England, as, for instance, Portland cement. The blocks were not laid in masonry, but were piled on each other, so as to present the greatest number of angles to the water, in order to break its force. That system had been, he believed, usually adopted in France.

Mr. MURTON remarked, that the lime used in these works came from Theil on the Rhone, about 40 miles or 50 miles north of Avignon, and was probably one of the best limes in the world. The same quality of lime was used at Algiers, and at the Cherbourg breakwater.

Mr. WILLIAM PARKES wished to call attention to a curious case of depositing concrete in the sea, which had been executed by M. Pascal, the Engineer of the Marseilles works. It was the erection of a beacon about 5 miles distant from that port. The beacon had to be placed on a submerged rock, he believed about 5 feet under water. The plan adopted was to sink on the rock a kind of caisson, the sides of which were formed of movable planks set vertically, and each plank could be pushed up or down, so as to adjust itself to the inequalities of the rock. The concrete was then thrown into the caisson without other protection. This plan failed three times, but the fourth attempt was successful; and the concrete being brought up to the level of the water, the beacon now standing was placed on it. It was somewhat remarkable, however, that the same Engineer should have adopted, in the harbour-works at Marseilles, the system of blocks formed on shore, instead of depositing the concrete in a moist state, which had been so successful in the more exposed situation of the beacon, several

miles out at sea. M. Pascal was very cautious in the selection of the lime. From long experience, he had great confidence in the particular kind so largely used in the Marseilles harbour-works, but he did not by any means extend that confidence to other limes, though apparently of similar qualities. He appeared to consider that each description ought to be separately tested by lengthened experience.

Mr. HAWKSHAW, Past-President, said, the practice of passing concrete through water was not an uncommon one. He had passed concrete through 50 feet of water with perfect success. As far as his experience went, the concrete set quite as well under those circumstances as when it was deposited in the open air. He had done this both in salt and fresh water. The docks at Genoa were built in a similar way to that just described, viz., by sinking rows of small gauge-piles a few feet apart. The space was then lined with planking; and to prevent the lime escaping from the concrete, coarse canvas was put in, and sunk with stones to the bottom, so as to line the sides. As fast as the concrete was mixed, it was carried in baskets, and thrown into the water. In passing concrete through water, he had used a box containing about 2 cubic yards; when it reached the bottom, a bolt was withdrawn, and the concrete dropped out.

Mr. VIGNOLES mentioned, that about fifteen years ago, he built the foundations of a bridge-pier in the same manner. After various attempts had been made to get the water out, he threw in from 15 feet to 20 feet of concrete, till the mass deposited was sufficient to prevent the water rising beyond the capacity of the pumps to keep clear. He was thus able to get in a bed of concrete on which to lay the first foundation course.

Mr. C. REILLY said, that a mole was about to be commenced at Callao, to be carried out to a length of 900 feet, in 30 feet depth of water, 60 feet wide at the top, with a batter to the side walls of about 1 in 5. Mr. Prentice (M. Inst. C.E.), the Engineer to the Government, had adopted the following plan of construction, involving the extensive use of concrete in the submarine works: the mole would consist mainly of two outer retaining walls, formed of concrete from the base up to the level of low water, thence to the top of the quay the walls would be continued in ashlar, the interior hearting between the retaining walls being formed of shingle and gravel. The concrete walls would be about 18 feet thick at the base, formed of fresh concrete, and protected by a strong exterior face, or wall of cast iron. Owing to the nature of the bottom, which was entirely shingle, it was deemed impossible to drive iron piles with the requisite precision. It was therefore proposed to dredge a trench 4 feet deep along the base of each of the intended retaining walls, and within that trench to put in

strong cast-iron frames standing vertically, the largest, in the deepest water, weighing from 5 tons to 6 tons each. These frames, placed 6 feet apart, would be connected by strong iron tie-bars to the corresponding frames on the opposite side of the mole. The spaces, about 6 feet wide, between the adjacent iron frames, were to be closed with cast-iron corrugated panels, the combination of frames and panels constituting an iron retaining wall of sufficient strength to resist the thrust of the fresh concrete, and of the hearting. As the work proceeded, the trench at the foot of the iron wall would be filled up with concrete, thereby making a water-tight joint between the mole and the bottom of the sea. It was thought, that if the concrete walls were formed by tipping from above the top of the water, a good deal of the lime would be washed out, and float away; and Mr. Prentice had therefore decided to deposit the concrete by means of skips or boxes, which on being lowered to the bottom, would permit the concrete to escape by a self-acting arrangement.

Mr. JOHN MURRAY said, about two years ago he sent to the Institution a Paper on the Harbours in the Gulf of Lyons, but the arrangements for the remainder of the session having been completed, the reading of that Paper was postponed. He had requested it to be returned to him, with the intention of adding to it some remarks upon the Port of Marseilles, but he had been fortunately anticipated by the Author, who had contributed a valuable account of the internal arrangements of the warehouses, and of the hydraulic machinery of these extensive new docks.

The Paper, however, required correction in one point. It stated that the old harbour was a port since the time of Louis XV. Now the city was founded by a colony of Greeks about 600 years before the Christian era. It existed as an independent republic till the year 49 B.C., when it fell under the dominion of Rome. In the year 583 it was taken possession of by the King of France, from whose feeble hands it passed, in 980, into the power of hereditary Viscounts, and was not finally annexed to the Crown of France till 1481, under Louis XI. In 1669, Louis XIV. made it a free port; and it had since attained a high commercial position. It had rapidly increased since the conquest of Algiers in 1830; and it had become the station of the steam packets on the line between Malta, Alexandria, and Constantinople.

The area of the old harbour was about 65 acres. In addition there were 47 acres in the dock Joliette, 22 acres in the dock du Lazaret, and 64 acres in the docks d'Arène and Napoléon; making a total water surface of about 198 acres, exclusive of the outer harbour at the entrance of the port, of about 50 acres. He hoped the Author of the Paper would be requested to ascertain the population, at the last census, of the city and suburbs. In 1851 it

was 185,000. The port, in the state in which it was represented on the French chart, was situated in the bight of a bay; the length across from Cape Croiselle to Cape Méjean being 11½ miles, and the depth to Cape Risede being 6½ miles, with a very extensive fetch of sea across the whole Gulf of Lyons. This deep bay was, however, divided nearly in the middle by the islands of Ratoneau and Pomègues. In the south-eastern part of the northern bay, the old harbour was situated, within a natural inlet of the coast. But there was no protection whatever at its mouth to resist this great fetch of sea, and the new works were constructed entirely under the shelter of the mole Joliette.

At times no vessel could ride in the northern bay, nor lie in the outer harbour, nor pass from the old inlet into the new docks; consequently, after the Joliette mole had been constructed, some work should have been run out from the Pharo headland to shelter the outer harbour. The outer harbour of the docks d'Arène and Napoléon was still more exposed, and must ultimately be protected by a seaward mole. The bed of the sea, at right angles to the mole Joliette, for a quarter of a mile outwards, had a fall of 1 in 36; between a quarter and a half mile, 1 in 66; and between half a mile and a mile, 1 in 87, in 22 fathoms water. There must, therefore, be a considerable sea striking such an abrupt shore, and exposing the mole to a severe stroke from the deep water outside, and from such a long fetch of sea. The old harbour was surrounded on three sides by streets and buildings, rising from the margin of the quays in the form of an amphitheatre. The old quays were narrow and incommodious, occupied by building yards, depôts for timber, and other incumbrances, with very shallow water alongside of them; requiring, for the purposes of loading and unloading, the intervention of lighters, which not only occupied water space, but were the cause of great annoyance and inconvenience. This had been remedied by dredging the harbour, over its whole extent, rebuilding the quays with béton, on an uniform plan, having the foundations laid sufficiently deep to allow of ordinary vessels laying alongside them. But the sewage of the town, increased by the bilge-water from the shipping, stagnated in a still pool under a burning sun, and caused the emanation of unwholesome gases. Deposits of sand were also brought into the harbour from the sea. Dredging, therefore, was absolutely necessary, and was carried on to some extent to maintain the requisite depth of water for the shipping, and an intercepting sewer was constructed, in order to convey the noxious matter into the sea, free from the harbour. The new docks, being placed under like circumstances as regarded the sewage from the buildings rising up in their vicinity, would in time require similar treatment.

There was an adjacent harbour at Frioul of some importance,

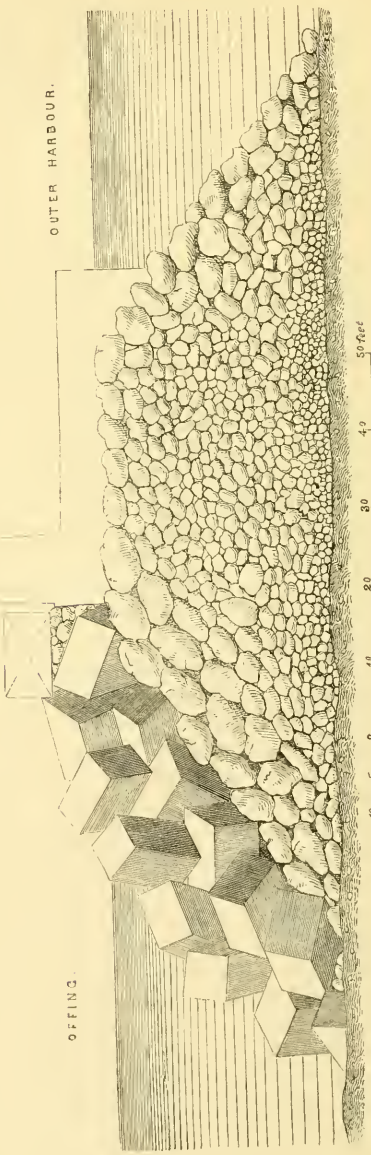
which had not been alluded to in the Paper. It was formed by connecting the islands of Ratoneau and Pomègues, by a solid mole of masonry, with another mole on the eastern side. This was the quarantine port, with a considerable depth of water therein and at its entrance, but subject to the stroke of the sea when the wind was from the south-west: at such times vessels lay very uneasily in this harbour, and it had a tendency to silt up, in consequence of the connecting mole being a solid structure. The anchorage in calm weather was in front of the port; but the great anchorage for men-of-war was in the roadstead of Endoume, in from 7 to 7½ fathoms of water.

Some remarks had been made respecting the disintegration of the béton blocks used at Marseilles and at Algiers. That subject had been already discussed; and upon reference to the Minutes of the Institution,[1] it would be found that he had stated some facts, extracted from the 'Annales des Ponts et Chaussées,' proving that the disintegration of the béton blocks was so trifling as not to be a matter of consideration. He could confirm, by inspection, what had been stated as to the old béton blocks at Leghorn not being more disintegrated than ordinary stone blocks when thrown into the sea. The new mole at Leghorn, now in course of construction, was, in his opinion, well calculated to resist the action of the waves. (Fig. 4, p. 174.) In front of the seaward side of the parapet, large masses of béton, weighing about 25 tons each, were all placed regularly, but isolated from the wall about 18 inches, and nearly the same distance apart from each other; giving gravity to the mass, breaking the force of the waves, and permitting the parapet to be of less strength than at Marseilles.

With regard to the expense of these breakwaters, the cost of the Joliette mole amounted to £215 per running yard, exclusive of the paved quay and inner wall, which, with the berm on which it rested, formed no part of the breakwater. The blocks were made from the lime of the Rhone, with sand and stones broken into small pieces. At Algiers a different system was pursued, inasmuch as no rubble deposit was used in the hearting or core of the mole, which was composed wholly of béton blocks, weighing about 25 tons each, and made with an admixture of pozzolano. In consequence, the price was greater and the labour was more costly than in France. The expense of the mole was about £366 per running yard. The depth at Algiers was from 6 to 9 fathoms; and at Marseilles, from 5 to 6 fathoms. He had seen nothing published respecting the cost of the Holyhead Harbour; but from the information he had received, the expenditure had been £1,500,000, for a breakwater 2,400 yards

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xviii., p. 136.

Fig. 4.



Profile of the New Mole at Leghorn.

in length, and in a depth of 5 to 7 fathoms, but with the head in 9 fathoms not yet completed ; thus bringing the cost to about £624 per running yard. The Dover pier, now in course of construction, in 7½ fathoms of water, cost £1,245 per running yard. That pier was formed with vertical walls from the bottom to the top, composed of concrete blocks, faced with granite ; and there was a heavy parapet on the sea side. The blocks were made in an open box, with timber sides and ends, and the béton was formed with Portland cement and sand, mixed with broken shingle, and, when partially indurated, the timber supports were struck, and the mass left to harden. Before concluding, he would draw attention to the use of brick blocks. His friend, Mr. Mylne, had consulted him with regard to the foundations of a bridge then about to be built at Nottingham, and he had advised the use of large moulded blocks of brick, laid in the usual manner with hoop iron bond, and when sufficiently hardened, to use them for the foundations of the piers. For this kind of work the cements used were blue lias and Portland. It was found that blue lias made good work, although the arrises were not so sharp as with the Portland cement ; but the latter was uncertain in its nature. If the material was good, compact blocks could be formed with that cement of excellent quality. The cost of the blocks at Marseilles, set in place, was from 5*d.* to 5½*d.* per cubic foot. He had arrived at the general conclusion, that the system pursued at that port was the cheapest that had been brought under the notice of the Institution.

Mr. Alfred Giles concurred in the opinion, as to the foul condition of these docks, situated in a tideless sea, without a current. There must be great need of sanitary measures, and, he apprehended, there must be a large amount of dredging to keep them open. With regard to the quay-walls of these docks, it had been stated that the blocks were laid upon rubble work, thrown in, and built up from the depth of 18 feet below water ; and it was said that some of these walls had failed and inclined forward, from causes which he could not gather from the Paper. It was evident that docks, with a depth of only 10 feet of water at the quay side, were not sufficient for modern shipping, and if the slope of the rubble mound projected far into the docks, ships of large tonnage could not use these quays. The price of £24 per yard for the quay walls was moderate ; but looking at the dock as a whole, the cost of the mole must be added, and that would make it very expensive. It was evident that the constructors of these docks and warehouses had had an Imperial purse to deal with. When a block of warehouses was stated to have cost so large a sum as half a million sterling, a comparison naturally presented itself with the cost of similar buildings in England. Each Marseilles warehouse consisted of eight floors, and the area of these floors was of course

the measure of its capacity; and, taking the cost at £500,000, the area of the buildings multiplied by 8 gave a cost of £42 per square of flooring. Any one who had constructed warehouses knew that to be a high price. He had constructed warehouses with four floors, and the cost was considerably less than half that sum per square of flooring. Taking it as a cube, the cost was 7*d.* per foot; that, he thought, was also a high price. A point of objection in these warehouses was the great height to which the goods must be lifted to reach the top floors, involving additional expense in working and greater risk from fire; and unless ground was extremely valuable, he could not conceive the utility of carrying up so many floors, the extreme height being no less than 117 feet.

It was stated in the Paper, that the trade of Marseilles was now estimated at about three million tons per annum; but with all that amount of shipping, it appeared that there were only two graving-docks, in which one hundred and sixty-six ships per annum were placed, or three ships per fortnight for each dock, showing a demand for a large increase in that description of accommodation. When it was considered that for the trade of London there were thirty-five graving-docks, besides the Thames Graving Docks, the limited accommodation at Marseilles would be obvious. On the subject of the construction of the mole, the question had been raised as to concrete. He thought, in such a place as that, it would be worth a trial to throw liquid concrete into the sea. He had made that experiment in 20 feet of water more than twenty years ago. The concrete was conveyed through a trunk to the bottom, and as the foundations rose, the trunk was gradually moved, so as to bring the whole to a level. He took up some of that concrete ten years afterwards, and found it to be so hard that it could scarcely be broken. Probably such an appliance in this case would have been as durable and less costly than the materials which were used.

Sir John Rennie, Past-President, thought the Paper deserved great attention. The Author had described the mode in which a large and important work had been executed. There were two subjects for consideration: first, the design of the work, whether it was fit for the objects for which it was intended; and, secondly, the mode of executing that work, whether it was the most economical and the best adapted for the purpose.

With the general design of making docks parallel to the shore, upon the whole, no fault was to be found; but he thought that the entrances were not well designed. The southern entrance, at times, was exposed to a heavy sea. No ship, during a storm from the exposed quarter, would make that entrance with safety; because, the moment she got within it, she would encounter the boiling sea caused by the perpendicular walls on two sides and the rubble-

work on the shore lying at an acute angle. Then, with regard to the northern entrance, that was also much exposed to the swell; and the sea, to a certain extent, produced the same effects. Therefore, he thought, as regarded one of the most important elements in designing a harbour of that kind, these entrances had not been well conceived. Next came the execution of the works. The practice of using concrete in moles was an ancient one. Concrete was found in the ruins of Carthage, in the Bay of Naples, at Ancona, Messina, and elsewhere. In all those places the system of concrete had been more or less adopted. The engineers of those days also employed the admirable material of pozzolano for that purpose, and were successful with it. In modern times that system had been carried out to a considerable extent; but he thought its employment in harbours might be dated from somewhere between 1830 and 1838. Soon after the French took Algiers, it was considered most important to improve the harbour; and M. Poirel, the Engineer of the works at Algiers, proposed a considerable extension; for that purpose he manufactured concrete blocks on a large scale, and built the foundations of the walls on the same system as had been described as having been practised at Marseilles; but he carried the system further. He dredged a trench at the bottom, and provided an apparatus, by means of which sacking was spread along the line of the proposed wall, and the concrete, mixed with a proportion of pozzolano, was poured into the sacks from above, and when the concrete had become sufficiently hard, the sacking was removed, and thus a continuous line of foundation was formed. The same Engineer also introduced the system of large blocks, made of concrete mixed with pozzolano, which was carried out to a great extent at Algiers. The expense, however, of these large blocks was at first demurred to by the French Government; for on examining the blocks it was found that the salt water had produced a material effect upon them. The cost amounted to nearly 5*s.* per ton for the small blocks, and to 8*s.* per ton for the large blocks, which were used outside the sea-wall at Marseilles. This was a high price, and it became a serious question (when it was considered that 2*s.* or 2*s.* 6*d.* per ton was a good price for natural stone), whether there was any economy in using these large concrete blocks. Then there was another important principle, which the French had endeavoured to establish. They said it was necessary to use blocks of at least 25 tons, which could not be moved by the action of the sea in the Mediterranean; but, looking to the cost of 8*s.* per ton for those blocks, it became a question whether, with stone on the spot at 2*s.* or 2*s.* 6*d.* per ton, it would not have been better to have made a flatter slope and to face it with rough stone, which they had at command, as by that means they would have formed a permanent face against the sea

at less expense. Works of this kind in the Mediterranean, where there was no rise and fall of tide, could not be compared with breakwaters constructed in situations where there was a rise and fall of tide varying from 12 feet to 30 feet, where the sea was heavier, and where it would become necessary to use larger blocks at a much higher price; and he would go further, and say, if the small material which was at hand were utilised and allowed to take a slope of 5 to 1, and if that slope were faced, it would become permanent. Therefore, in comparing the moderate cost of the breakwater at Marseilles with the cost of similar works in England, entirely different elements and circumstances had to be taken into account. It was very material whether there was a tide of 18 inches or of 18 feet to be dealt with. In some situations loose blocks of stone of from 15 tons to 17 tons each had been removed by the violence of the waves from one side of a breakwater to the other. In fact, there was no analogy between the works at Marseilles and those of any harbour in Great Britain.

The system of concrete blocks, he thought, might answer in many cases; and he inclined to the opinion, that that system of construction might be carried to a greater extent in this country than had yet been done, particularly on those parts of the coast where it was difficult to get solid blocks of stone of the requisite specific gravity. Concrete blocks might also be used with advantage in the hearting, having the outside cased with hard stone of the requisite size.

Mr. J. B. Redman said, Marseilles had the reputation of being the most ancient commercial town in Europe, and was a kind of link between the past and the present. The increase of the trade of the port during the last sixteen years might be taken as 50 per cent. In 1848, the exports and imports amounted to 2,000,000 tons, and in 1864, to 3,000,000 tons. The tonnage of London in 1848 was 3,000,000, and in 1863, 6,032,000, being an increase of 100 per cent. The tonnage of Liverpool had increased within the same period from 3,000,000 tons to 5,300,000 tons, being an increase of 70 per cent. With these figures as a datum for comparing Marseilles with London and Liverpool, it was a startling commercial conclusion, that with all the enormous tonnage, the dock had not been remunerative. Every Englishman must feel a deep interest in Marseilles, from the connection of that port with the overland route to India; and, in all probability, the large export and import tonnage was much made up by the steamers of the Messageries Impériales and others, in carrying the mails and baggage in connection with that route; and he presumed that the tonnage was calculated from the absolute entries and departures of vessels, as in London, with which, of course, the Marseilles tonnage was not commercially comparable.

He had endeavoured to arrive at some conclusion as to the total cost of the works, and the price per acre of area. According to the Paper, it would appear that there had been an expenditure of 30,000,000 francs upon the dock works, exclusive of the breakwater; and 40,000,000 francs had been voted to complete the same, exclusive of the graving-docks, which were estimated at 9,000,000 francs; while 4,000,000 francs was the estimate for the machinery for the docks. The aggregate cost of the breakwater was not stated, but assuming the length to be 2,000 metres, at £300 per metre, it would cost £600,000 or 15,000,000 francs—thus making a total cost of no less than 98,000,000 francs, or nearly £4,000,000 sterling. Taking the area of the respective docks to be—Joliette, 47 acres, Lazaret 28 acres, Napoléon 28 acres, and Impérial 30 acres, it gave a total area of 133 acres. He was afraid, upon referring to the drawings, that that was under estimated; but assuming that there were 150 acres, with that expenditure, the cost would be nearly £30,000 per acre of water area; which was not large compared with some of the more expensive docks of London and Liverpool, although in the latter cases the works were constructed with a rise of tide of 18 feet in the Thames and of 26 feet in the Mersey, whereas the works at Marseilles were executed in a tideless sea.

In London, prior to the formation of the Victoria Docks, the average cost for 300 acres of water, including warehouses, on a capital of £11,000,000, had been from £30,000 to £40,000 per acre. But the East and West India Docks, of 130 acres out of the above, had not cost half that amount.

The cost of the breakwater, at the average price by the Author's statement of £300 per metre, or £328 per yard, was, in a depth of water of 30 to 40 feet, £109 per foot run; as compared with Portland, £116 to £120 per foot, in from 50 to 60 feet water at low water, and 7 feet rise of tide, with convict labour; Alderney, £150, in 20 feet water at low water, and 17 feet rise of tide; and Dover, £360 on the entire length, in from 40 to 50 feet water at low water, and 19 feet rise of tide.[1] The quays at Marseilles seemed to have cost £8. 15*s.* per foot run, which, from the Paper, appeared to be exclusive of, and in addition to, the above quoted price for the breakwater. The warehouses, he found, contained 17,269,200 cubic feet English, and the cost amounted to 7*d.* per cubic foot, not a high price for warehouses of that kind; but allowing for the

[1] The Dover and Portland breakwaters would, therefore, be nearly twice the height of that at Marseilles, and that at Alderney about the same height, from the base. The breakwater at Plymouth was one mile long, in from 40 to 45 feet water at low water, with 16 feet rise of tide, and about 4,000,000 tons of stone had been deposited in that structure. It had cost more than £200 per foot run.—J. B. R.

internal courts, it was nearer 10*d.* per cubic foot. The canal communication between the old port and La Joliette had been turned into a temporary dock. In the aggregate, the cubical contents of these docks were 35,525 yards at £31,200, or 17*s.* 6*d.* per cubic yard of internal capacity, which was a high price. He had lately assisted in undocking a vessel of 1,900 tons burthen from an altered and enlarged dock just completed, the cost of which was not much more than half that price; the sides were of concrete and timber, and the head and wings of brickwork, but the entrance and gates were already in existence.

With reference to comparisons of foreign and British works for defending tidal slopes, undoubtedly the works in the Mediterranean, with a tideless sea, and the thermometer never below a certain temperature, were not likely to be influenced by such deteriorating causes as in this country. Although he had himself successfully used fluid or liquid concrete in large quantities, for the foundations of piers and wharf walls below low water, both in the lower and upper reaches of the Thames, still, he could point to instances of the non-success of concrete in the Thames, especially in the foundations of the Greenwich Pier, which he had several times reported upon and repaired; also in the case of a long river wall at Woolwich. He could not, however, in either instance speak to the quality of the lime. The wall at Woolwich had been built entirely of concrete, which had to be faced with ashlar, from the concrete flaking off between wind and water. Concrete sea walls at St. Leonard's (Hastings) and at Walton-on-the-Naze (Essex), had also succumbed to the attacks of the sea; in these cases there might have been structural defects. The case of Algiers had been referred to; and evidence respecting the decay of that breakwater would be found in the Harbours of Refuge Report of 1846. It would appear that at Marseilles, the extensive failure of the quay walls arose either from some structural defect, or from a greater settlement of the rubble base than was anticipated.

Mr. G. W. Hemans remarked, that the fact of these works having been executed in a tideless sea, had been alluded to as a circumstance which should render them easier of construction than those works which were carried out in situations where there were high tides. He confessed he could not agree with that opinion as applied to all works in water, because it appeared to him, that a tide which went down 20 feet or 25 feet below the fixed level to which it was required to build, gave a better access to the work than could be the case with a constant and uniform level of deep water. The works at Marseilles had been carried out in comparatively deep water which was subject to waves of great height and power; and, moreover, the water was always on the work at the summit, so that great injury might be done by the waves at a

critical part of the works, whereas, if there were a receding tide, a storm might often pass over during the ebb and leave the works uninjured. It was worthy of consideration, therefore, whether it was not an advantage in some undertakings to have the tide leaving the work exposed during certain periods, so as to obviate the necessity of the use of the diving bell or coffer-dams to a certain depth below the top.

Mr. HENDRY said, he found it stated in the Paper that in the experiments made with the hydraulic machinery in these docks, only 45 per cent. (or 315 lbs. per square inch) of the indicated accumulator pressure (700 lbs. per square inch) was obtained, which was a startling result after the experiments that had been made with this description of machinery. At St. Katherine's Docks, on an indicated pressure of 600 lbs., there was an effective pressure of nearly 500 lbs.; and on 700 lbs., there was about 580 lbs. effective pressure. Therefore, at the Marseilles Docks, there must either have been some error in the gauge, or the machine operated on must have been in a defective condition. He should state that only some portions of the hydraulic machinery were supplied by Sir William Armstrong and Co. as a guide in making the machines. At the time these hydraulic machines were first constructed, it was usual to allow on a 700 lbs. pressure, 420 lbs. as effective, and it was found, that old machines, made ten or twelve years ago, gave a much higher figure than that. He apprehended that the experiments quoted in the Paper must have been made on a single-acting machine—that was, a cylinder simply with a ram; and it was admitted, that in such a system, a great quantity of water was expended in proportion to the power exerted when lifting loads below the maximum; but in the double- and treble-acting machines, the quantity of water expended was much less in proportion to the load lifted. In hydraulic machines, however, any loss of water was more than compensated for by the fact, that no power was consumed except at the instant of lifting. In experiments with hydraulic cranes, to lift loads of 12 cwt., at Haydon Square, London, a load of 8 cwt. was lifted 60 feet in 6 seconds, or 10 feet per second; but the usual working speed was from 4 feet to 6 feet per second on the lifting chain. At the wagon hoists on the Blackwall Railway, loaded trucks, weighing 13 tons each, were lifted 22 feet in 12 seconds. At St. Katherine's Docks, a 30-cwt. crane discharged from a vessel, in eight hours, 2,030 boxes of sugar, weighing, in the aggregate, 460 tons; and in another instance, 7,020 bags of seed, weighing, in the aggregate, 560 tons, were lifted 85 feet in eight hours. He found, comparing hydraulic power with the most favourable conditions of manual labour in discharging cargo at Cotton's Wharf, London, that the average working of hand-power cranes required eight men at the handles to lift

a weight of 10 cwt., working twenty sets per hour, or 10 tons per hour raised to a height of 40 feet, at a cost for labour of 2*s.* 8*d.* per hour. By the hydraulic crane, with one man at 4*d.* per hour, thirty-six lifts, of 15 cwt. each, were made per hour; in other words, 27 tons were raised 40 feet high for a cost of 4*d.*, so that, under the most favourable circumstances, of hand-power (which costs, on an average, from 4*d.* to 6*d.* per ton), the cost was about $3\frac{1}{4}d.$ per ton; while with hydraulic power, the cost was under a farthing per ton for labour in working the crane. Mr. Hendry repeated his conviction, that there was either an error in the gauge, or that the machine itself was defective, looking to the results which had been invariably obtained with these machines in this country. He considered there was nothing in the nature of the machinery to produce such results as had been stated by the comparisons given in this Paper. In stating the cost of working Hydraulic Cranes, he should have added the wages of the engineer, fireman, and oiler, which he estimated at about £4. 15*s.* per week; this, added to 6 tons of coal, would bring the cost to about £10 per week for twenty cranes. The cost of hydraulic machinery, allowing for capital and every charge, certainly did not exceed, under unfavourable circumstances, 2*d.* per ton lifted. At Cory's Wharf, at the Victoria (London) Docks, the hydraulic cranes discharged coals at the rate of from 40 tons to 50 tons per hour, and he believed the cost to be under a 1*d.* per ton. He thought an average might be taken of $1\frac{1}{2}d.$ per ton.

Mr. Fowler, V.P., said, the point of interest was the comparison between the effect of the hydraulic machinery at these docks and the direct acting rotary hydraulic engine with three cylinders. It appeared that the result of the experiment had been the exertion of 45 per cent. of power in the one case, and of 65 per cent. in the other.

Mr. John Grant thought the importance of the subject of hydraulic machinery rendered it deserving of a special Paper, and he should much like to hear it discussed in its economical bearings. With regard to the remark that Portland cement was not always to be depended on, he would state, that during the last five years he had used about a million and a half bushels of Portland cement, and had tested it by more than ten thousand tests. He could speak with the utmost confidence as to the degree of reliance which might be placed upon that material. With regard to the question whether concrete answered best in salt water or in fresh water, he would state, as the result of his experience, that he found concrete stronger in salt water than in fresh water, and in no case weaker. In the docks at Marseilles, the foundations of the walls would have been more to be depended upon, if the concrete had been put in loose, instead of in manufactured blocks, kept in place only by

their own weight. One circumstance which struck him in looking at the sections of the walls was, that there seemed to be no headers or bonding-blocks going into the backing to tie the work together, and there seemed to be no batter whatever to the wall itself. He was not, therefore, surprised at the statement in the Paper, that the blocks, as well as the wall, inclined over towards the docks. He thought the weak point in these walls was their foundations.

Mr. JENNINGS remarked, that the importance of Papers like this consisted in their practical effect on works in London and elsewhere. It had been objected, that the warehouses at Marseilles were carried up too high. From his experience in warehouses he had built, he did not share in that objection. If it took only 25 seconds or 30 seconds to raise goods to the top of warehouses of ordinary height, a few seconds more would serve to raise them considerably higher, and that was not a matter of importance in connection with the capacity of such buildings. But there was another point, and an important one—viz., that when warehouses were carried up to a great height, so much more strength of material was required, that the economy of that plan of building them was doubtful, unless the ground space was extremely limited. Another point was, that though these warehouses were stated to be built of fireproof materials, similar buildings would appear to be very unsafe in London, as the large amount of goods accumulated in one place, in the event of fire, destroyed the whole by the intensity of the heat, though every material of the building were incombustible. Respecting the use of concrete blocks, he had lately heard that in the Bay of Biscay, blocks of 40 tons were used. This fact might make a material difference in the cost of the works. The blocks at Holyhead were of considerable size, and that circumstance might tend to add to the cost of the work.

January 31, 1865.

JOHN FOWLER, Vice-President,
in the Chair.

The discussion upon the Paper No. 1,121, "Account of the Docks and Warehouses at Marseilles," occupied the whole evening, to the exclusion of any other subject.

February 7, 1865.

JOHN FOWLER, Vice-President,
in the Chair.

The following Candidates were balloted for, and duly elected:—ALEXANDER BEATTIE, ZERAH COLBURN, WALTER ROBERT KINIPPLE, WILLIAM NETHERSOLE, DANIEL BADDELEY PRITCHARD, WILLIAM HUMFREY RANKIN, and JOHN RICHARD RAVENHILL, as Members; EMANUEL ALLEN, RICHARD AYLMER, CHARLES BARCLAY, JOHN HICKMAN BARNES, ALEXANDER RICHARDSON BINNIE, JAMES BRAND, WALTER BROCK, Captain RAFAEL CERERO, WALTER GIBBONS COX, HENRY ALLASON FLETCHER, JOHN HEAD, HENRY TEMPLE HUMPHREYS, ALEXANDER CARNEGIE KIRK, HENRY LEE, Jun., JOHN CHARLES LEWIS LOEFFLER, FREDERICK THORPE MAPPIN, JOSHUA LLEWELYN MORGAN, MATTHEW ANDREW MUIR, GEORGE GORDON PAGE, JOHN RICHARDSON, THEODORE ANTHONY ROCHUSSEN, HENRY ROSE, THOMAS VAUGHAN, WILLIAM STANLEY WHITWORTH, GEORGE WYTHES, and GEORGE EDWARD WYTHES, as Associates.

No. 1,123.—"The Chey-Air Bridge, Madras Railway." By EDWARD JOHNSTON, M. Inst. C.E.

THE River Chey-Air presents the usual features met with in nearly all the large rivers of Southern India. The banks are generally low, and ill defined, and the bed, for almost the entire width, and to an unknown depth, consists of clean sharp sand. For nine months during the year the bed is perfectly dry, being subject only to heavy floods in the months of May, June, and November, but, even during the driest seasons, the substratum is always highly charged with water to within 2 feet or 3 feet of the surface. This fact, added to the great depth of the sand, constituted the main difficulties to be overcome in constructing the foundations of this bridge.

The bridge is situated on the North-West Line of the Madras Railway, at a distance of one hundred and forty-three miles from the Madras terminal station. The extreme width of the river at the point of crossing is 3,320 feet from bank to bank, the drainage area being about 2,272 square miles, and the fall in the stream at the rate of 11 feet per mile. At a distance of twenty chains above the bridge, the river separates into two distinct channels, the

southern being the principal one, and at the point of crossing, it is about 1,600 feet in width; then the bank dividing the two channels occurs, between the 20th and the 21st piers, and has a width of 464 feet, and next the northern channel, 1,256 feet in width. The highest point of the bank in the channel is 5·57 feet above the bed of the river, and 2·27 feet above the general level of the land through which the line passes, for upwards of half a mile on each side of the river. As it was ascertained, that the highest known flood only covered the bank to a depth of 14 inches, it was decided to substitute an earthen embankment for a masonry viaduct on this portion of the work, and to span the Chey-Air, by two distinct bridges; that on the south consisting of twenty-two openings and that on the north having sixteen openings, each 70 feet span from centre to centre of the piers.

The piers were built of masonry laid on timber platforms, placed within dams, at a depth of 15 feet below the bed of the river, the water being pumped out during the progress of the work, by means of Piccotah pumps, placed around the dam, and worked as hereafter described.

In order to commence the work at the lowest possible level, the sand, over the site of the intended dam, was in the first instance removed, until the water was reached. Within this space the dimensions of the dam, 52 feet by 22 feet, were set out, when piles, 9 inches square, were driven at intervals of 10 feet, to a depth of 18 feet, the heads being cut off level with the water. The piles were secured by waling-pieces, and were strongly braced across. Close planking, 2½ inches in thickness, was next let down behind the piles, and the space around was backed up with clay and grass sods, to prevent the sand from slipping in. Afterwards the Piccotah pumps were fixed at intervals of 3 feet along three sides of the dams, being supported on sleepers, bedded on clay, one end of each sleeper resting on the waling-pieces. About sixty men removed the sand within the dam with baskets, which were handed up as they were filled, to women and children, who carried it clear of the work: in this manner the excavation was proceeded with, until the required depth was reached, when the ground was carefully levelled, ready to receive the timber platform. Advantage was taken of the fall in the river, of 11 feet per mile, by cutting a channel from the dam, commencing at a depth of about 5 feet, and terminating on the surface, at a distance of 50 chains down the river, thus reducing the lift, from 15 feet to about 10 feet. As the excavation proceeded, the water in the dam was removed by thirty-six Piccotah pumps, which delivered the water raised by them into a wooden trough that surrounded the dam, whence it was conducted into the above-mentioned channel.

Plate 10, Fig. 1, exhibits the plan of a foundation, with the position of the Piccotah pumps, and wooden troughs for conveying away the water. Plate 10, Fig. 2, is a section, showing the Piccotah pumps fixed, the excavation and timber platform complete, with the masonry built upon the latter.

The Piccotah pump is much used in many parts of Southern India for irrigation purposes, and has been generally adopted by the Engineers of the Madras Railway for pumping out the water from foundations, for which it has been found to act in a satisfactory and efficient manner. It consists simply of a balance lever, one end of which is weighted by a man walking up and down the lever, while to the other end a bucket is suspended by a long bamboo; another man standing on a staging in the dam, guides the bucket, and fills and empties it. The bucket generally in use is 19 inches in diameter, and 12 inches in depth; it is made of thin sheet iron, with a curved bottom, and is capable of containing about 5 gallons. Two well-trained men will raise, on an average, about 35 gallons per minute, where the lift does not exceed 9 feet or 10 feet. At the Chey-Air Bridge it was found necessary to use at each dam thirty-six of these pumps, worked by a gang of seventy-two Coolies, who were relieved every six hours, and who raised, on an average, 1,260 gallons per minute, the mean lift being from 7 feet to 8 feet.

The timber platforms are entirely of aucha and eloopay, both close, hard-grained woods; and being placed at a depth of 15 feet below the bed of the river, where they are protected from the alternate action of air and water, it is believed they will be very durable. These platforms are 42 feet in length by 13 feet in width; the main beams and transverse pieces are 12 inches square, and are strongly scarfed and bolted together; over these there is a flooring of sleepers 10 feet long by 10 inches by 6 inches in section, spiked down with 12-inch jagged spikes. On this flooring, the masonry is constructed, in heavy courses of well-bedded stones, each varying in size from $\frac{1}{2}$ to $\frac{3}{4}$ of a cubic yard, built in hydraulic mortar and well grouted, to within 18 inches of the bed of the river, and therefore about 18 inches above the lowest level to which the water subsides in the sand, during the dry season. Above this point the fair work of the pier commences. Careful levels were taken during the progress of the works, but as the sand was exceedingly compact, no appreciable settlement took place after the first course of masonry was laid.

The piling and the timber around the dams have, in every instance, remained undisturbed; and the space between them and the masonry has been filled in with waste stone to a depth of 9 feet, in order to provide against the possibility of any scour

taking place during heavy floods. The works have withstood the monsoons of three years, without showing the slightest indication of any scour; in fact, after heavy floods, no alteration takes place in the bed of the river; and it was observed, that even the centre pegs for this bridge remained undisturbed for upwards of two years, previous to its construction.

The stone used for the foundations was obtained from a quarry of hard, slaty, magnesian limestone, and was raised in large blocks. The quarry was situated about 25 chains from the south abutment, and a communication with the works on the north side was effected, by means of a temporary railway, $1\frac{1}{4}$ mile in length, carried along the bed of the river, parallel to, and within 70 feet of the bridge. The stone from this quarry, as well as all other building material, was conveyed along this line to the works.

The upper part of the piers is built with a light-coloured magnesian limestone, obtained from a quarry situated $2\frac{1}{2}$ miles from the works, on the north side of the river. It was delivered on the works by a native contractor, at the rate of 5*s.* 6*d.* per cubic yard, subject to a deduction of $\frac{1}{7}$th for bad stacking.

The total cost of preparing a single dam, with timber platform complete ready to receive the masonry, was:—

	£.	s.	d.
Pile-driving	24	3	6
Excavation	38	13	0
Pumping	50	2	0
Timber platform . . .	37	9	0
Total . .	£150	7	6

The average number of workpeople, of all classes, engaged daily on the works, amounted to about 4,049, at the following rate of wages:—

310 stonemasons and stonecutters,	from	$7\frac{1}{2}d.$ to 1*s.* 3*d.*	per day.
80 carpenters	„	$7\frac{1}{2}d.$ „ 1*s.* $1\frac{1}{2}d.$	„
24 sawyers	„	$10\frac{1}{2}d.$ „ 1*s.* $1\frac{1}{2}d.$	„
15 blacksmiths . . .	„	$10\frac{1}{2}d.$ „ 1*s.*	„
15 hammermen		at 6*d.*	„
15 bellows boys		„ 3*d.*	„
340 Piccotah pump coolies . .		„ 9*d.*	„
200 quarry coolies		„ 6*d.*	„
1,100 coolies	from	3*d.* to $4\frac{1}{2}d.$	„
1,950 women and children . .	„	$1\frac{1}{2}d.$ „ $2\frac{1}{2}d.$	„

The Chey-Air Bridge contains 16,320 cubic yards of masonry, consisting of coursed work, quarry-faced, with chiselled-setting margin, and it was executed at a cost of £18,681. The works were commenced on the 13th of August, 1860, and were completed ready to receive the girders on the 16th of January, 1862,

thus occupying little more than sixteen months in their construction.

The character of the work yet remaining to be done, will be merely a repetition of what has already been executed in the case of several large bridges on the same line of railway. In illustration, the superstructure of the bridge over the River Cavery will be described, the spans being the same, and all the essential particulars very similar. The girders are continuous over two spans, and are thus 140 feet in length. They are ordinary boiler-plate girders, so proportioned as to give a maximum strain of 5 tons per square inch in the extended parts, and of 4 tons per square inch in the compressed parts. Each length of 140 feet is composed of three portions; the central one is 30 feet in length, and has its centre over the middle pier, while the two ends are each 55 feet in length, and extend to the centres of the two adjacent piers. The position of the joints was determined by calculation, as being at about the mean position of the points of contrary flexure, in various states of distribution of the load. The three pieces were connected together on a platform adjacent to the abutment; and when this was accomplished, the two girders were connected by cross bracing, and by a system of longitudinal bracing, formed of a 'herring-bone' arrangement of half timbers, bolted to the under side of the cross-bearers, by which the rails were carried. It was found, by experiment, that when the ordinary T-iron cross-bracing alone was fixed, the vibrations of a pair of girders could be increased to about 5 inches, by the application of a moderate lateral force isochronous with these vibrations; whilst on the addition of the herring-bone bracing, it became impossible to produce any appreciable vibration by such means. For the purpose of getting the girders into their places, at the top of each pier two frames were erected, each carrying two rollers in the lines of the centres of the girders. To the underside of the latter rails were attached, with their running faces downwards. The girders were first lifted, by jacks, from the platforms, when several rollers were fixed on the platforms, upon which they were let down. They were then hauled forward by a powerful crab tackle placed on one of the piers in advance, and so were ultimately taken to the further end of the bridge; the remainder being similarly hauled over in succession. Having thus always two bearing points, with the centre of gravity between them, there was no tendency to tilt, and no necessity for staging or scaffolding—a material advantage in the case of rivers subject to sudden floods of extreme violence.

The above description of the superstructure of the Cavery Bridge may stand for that of the Chey-Air, the girders for which are, with

some trifling variations of detail, made from the same designs, and the method of fixing which will be precisely similar.

This mode of bridging the larger rivers throughout the extent of the Madras Company's works has been found so certain and effectual, that scarcely any variation has been made from it since its original adoption in the case of the bridge over the River Palar, on the south-west line, about 100 miles from Madras, of the construction of which bridge the Author also had charge.

The communication is accompanied by three diagrams, from which Plate 10 has been compiled.

[Mr. J. M. Heppel.

Mr. J. M. Heppel said, he believed he was chiefly instrumental in introducing this class of bridge on the Madras Railway, and perhaps it was desirable that he should briefly state the considerations which led him, and those who were then connected with him, to select it in preference to others.

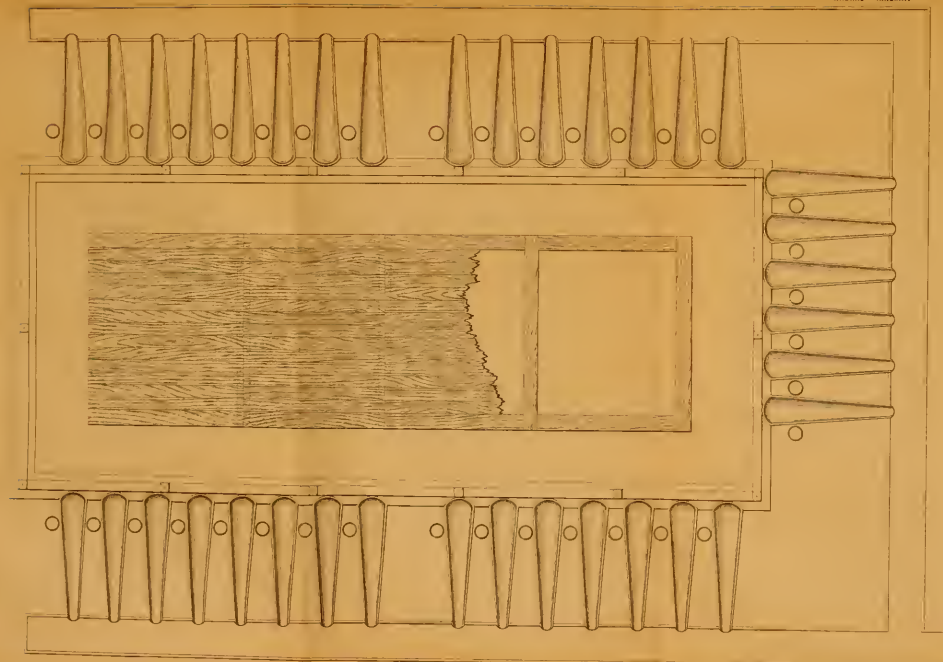
The Madras Railway consisted of two main lines, one of which ran south-west, and the other, branching from the first a short distance from Madras, ran to the north-west, where it would ultimately join the great Bombay line. Between these two lines, as between two arms, was embraced all the table land of Mysore extending to the east, from the main range of the Western Ghâts. All the main rivers crossed by either of these lines, derived the greater part of their waters from the feeders which descended from the Mysore territory; in fact, a small area of land in the neighbourhood of Nun-dy-droog, in Mysore, near the great military station of Bangalore, would be found to embrace the principal feeders of nearly all these rivers, all of which discharged on the eastern coast. On the southern side were the Cavery, the Panar, and the Palar; towards the north, there was the Penair, one of the main tributaries to which was the Chey-Air, and next, the great river Kistna, of which some of the chief tributaries were the Hugry and the Tungabudra, descending northwards from the Mysore Hills, and crossing by the north-west line. The rocks forming the framework of the elevated country were chiefly of the primitive character, gneiss principally predominating. Without entering into any geological theory, it was tolerably apparent, that the softer materials, constituting the plains and valleys of the neighbourhood, were greatly made up from the detritus of these primitive rocks. The river beds had accumulated in them the quartz and siliceous particles—the softer ones being washed away—to a depth which in most cases might for practical purposes be considered unlimited, because it was greater than that to which it was practicable to carry foundations. These rivers were particularly liable to quicksands, which he fancied in some degree arose from their rapid fall, there being a constant undercurrent of water, even when the river courses were dry; for at the driest time water was found within a few feet of the surface, and was constantly percolating through the mass. Quicksands therefore abounded, as the result of the local inequality of the hydraulic equilibrium producing a kind of spring; but the greatest disturbance of the sand took place during the floods, which, some annually, and some biennially, descended from the mountains. The extent to which the sand was set in motion by these floods was known to be great, but it was generally extremely difficult to obtain any measure of the depth to which it was disturbed.

Such was the state of matters when, in the year 1857, he took

Fig 1

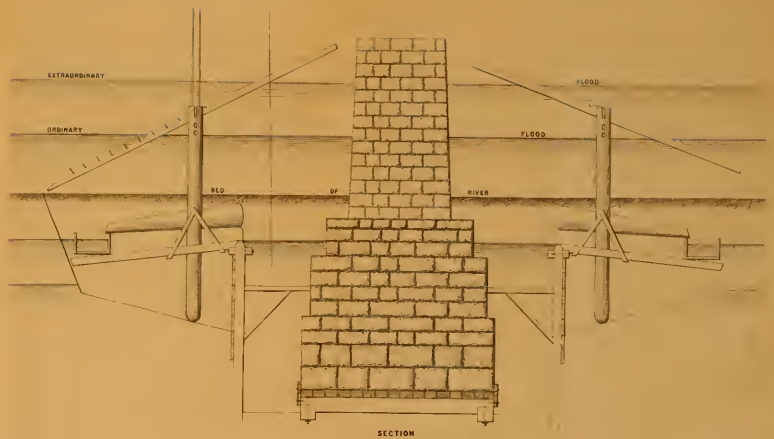
THE CHEY-AIR BRIDGE.

MADRAS RAILWAY.



PLAN

Fig 2



SECTION

Scale

charge of the works on the Madras Railway, and there was much discussion as to the best mode of bridging some of the large rivers. If the question had arisen in England, or in almost any part of the continent of Europe, it would have been comparatively easy of solution, for he had never seen cases better adapted for the employment of iron cylinders; but the great difficulty in the way of the use of these, or of iron piling, was, in the first place, getting the materials from England within reasonable time, and in the next place, when obtained, conveying them along the rude roads of the country; therefore it was thought desirable, if possible, to use the materials of the country.

There was another method of making foundations in India which had been in many cases successful, that of wells, on which a Paper had been read by his predecessor, Mr. Bruce;[1] but from all he could learn from the direct experience of those who had applied wells for similar purposes in Madras, that method did not appear to have been so completely successful in practice as the accounts of their application in other places would have led him to believe; so that with the information he then possessed, he felt some hesitation in using them, not feeling perfectly confident of the result. It happened that at that time the Author had charge of a large bridge over the Goriattum river, one of the chief tributaries of the Palar, and which also took its rise in the Mysore country, and the success which attended the application of the means described in the Paper was very striking. By taking advantage of the favourable season, by keeping steadily at work with a large force of labour, and by applying the native method of draining the foundations, by means of the Piccotah pump—taking advantage also of the rapid fall of the river to drain the excavations by natural means to as low a level as possible, Mr. Johnston was getting in the foundations of the bridge rapidly and well, and felt confident that in all similar cases he could lay the foundations 13 feet or 14 feet below the level of the bed of the river without having recourse to any means beyond those afforded by the country for drainage, and with only so much timbering of the excavations as would suffice to prevent the sides falling in. The suggestion was a valuable one, and Mr. Heppel took pains to convince himself that 14 feet would be sufficient. The balance of evidence was in favour of it; and although at the time there was some degree of uncertainty in fixing on this or any depth, subsequent experience seemed to have confirmed this conclusion. The foundations which were got in, in the way described, had stood the test of several years, and it did not appear that the disturbance of the river bed by the floods had been sufficient to cause injury of any

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xvi., p. 449.

kind. He believed the success of such an operation depended, to a considerable extent, upon the personal qualifications of the engineer in charge of the work; for it required the most unremitting attention, and involved keeping perpetually at work large bodies of native workmen, with the knowledge on their part that their own share in it was so important, that if they ceased, considerable difficulties and increase of expense would be the result; and, according to his experience of the native workmen, the knowledge of that fact alone was an almost irresistible temptation to strike. No one possessed a larger share of the talent of keeping these large bodies of native workmen under good discipline than did the Author, and it was greatly due to that qualification that so much success had attended his work.

The advantages which were gained by adopting this class of bridge could be briefly stated. In the first place, the power of utilizing the materials—timber, stone, and bricks—which were at hand in the country, without sending abroad for anything, and thus the foundations of the bridges (which were the things most desirable to commence the earliest) could be got in with the least possible delay. Next, by means of the iron superstructure, the quality of lightness was obtained, and undue pressure on the foundations of the piers was avoided, whereby the settlement to which there was always some degree of liability, from the uncertain nature of the beds of the rivers, was rendered less probable; and the slight settlement of piers supporting a continuous iron girder would have a less prejudicial effect than would be the case with stone or brick arches. The span of 70 feet was chosen, as being that which would, on the whole, produce the best balance of economy between the expense of the superstructure and that of the piers: it would hardly have been practicable to have had a larger span on account of the unwieldiness of the girders, which would have prevented their being got over in the way described in the Paper. The girders were all put together in lengths of two each, on the side of the bridge, and then hauled over to their several positions on rollers. By this means all scaffolding was dispensed with, which, in a river subject to sudden and heavy floods, was a point of great advantage. He therefore thought these bridges might be recommended for passing rivers of the character which were met with in Madras, and, as far as he had been able to ascertain, in tropical climates generally.

He might mention, in connection with these bridges, an arrangement, the object of which was, that if there should be any unforeseen delay in building the piers in a wide river like this, there might be something at hand to prevent that delay becoming excessive. The method was to make a frame of screw-piles which might be easily got in, and substituted for a pier. A central screw-

pile, about 5 inches in diameter, was pitched under the centre of each girder, and two cast-iron frames were keyed firmly to it at different levels. These were square in plan, and at each corner was a kind of plummer-block covered by a strap, forming a round collar, into which another pile might be slipped. At the four angles raking piles were pitched in this way, and the collars keyed over them, and then the four piles were screwed down till the whole came level with the central pile. On the top of that, the casting was fixed, and then came another plate with an upper bed to receive the girder, the top plate being able to be turned in any direction, so as to remedy any inaccuracy in putting the piles in their proper places. The only precaution to be observed was, that the two central piles were properly pitched at the exact gauge of the girders, and all the rest followed. This was a simple contrivance, and during the time he was in India he had some of those piles sent out (with the consent of Mr. Hawkshaw, the consulting Engineer) in case of emergency. It was not, however, in his time that occasion occurred for using them, but he had since been told that by their means had been renewed, in three months, the communication over an extensive breach in the line, caused by the bursting of a bank dam, which, but for this contrivance, would probably have taken nine months to restore. He had also been informed, that it was intended to apply that form of construction to a permanent bridge over one of the great rivers on the western coast; and that bridge being nearer to the sea, the objection to the use of iron, on account of the difficulties of transport, did not apply in the same degree.

It might be thought that he had said too much about a bridge which presented no very marked features; but the ease with which it was constructed, under circumstances which gave rise to some embarrassment, made it perhaps not altogether unworthy of attention on the part of those who had to carry out works where similar obstacles were met with. It was due to General Johnston to state, that it was in a great measure owing to the prompt and unprejudiced consideration given to all matters, however new, which were laid before him during the time he filled the office of consulting Engineer for railways in Madras, that this and similar works had been carried to so successful an issue; and it might be said generally of the Corps of Royal Engineers in Madras, that there was no body of men more willing to entertain practical suggestions, to impart freely the results of their own experience, or more ready to appreciate the responsibilities and aid in overcoming the difficulties of others.

In reply to questions, Mr. Heppel said, the main reason for the preference of the boiler-plate girders was, probably, that when he was in India he understood that form of construction better than

any other. The weight of the heaviest piece of ironwork was about 4 tons; but none of the girders were conveyed by the ordinary roads during the time he was on the works; for when once the piers were up, the putting on of the superstructure occupied very little time, and the girders were then conveyed to the bridge on the completed line. The number of dams in operation at one time was probably five or six. With respect to a suggestion of the advantage in economy which might have been gained by the use of concrete for the foundations, one objection was, that though lime was abundant, gravel was scarce.

Mr. WALKER, Managing Director of the Madras Railway, said, with regard to the depth of the sandbeds, he understood the Author to state, that he had bored to 100 feet in some of these beds without getting below the sand.

Mr, GEORGE BERKLEY hoped that this Paper would be followed by others, containing details of works carried out in India and other parts of the world, together with a description of the native appliances with which those works were executed. It was interesting to observe the early mechanical means adopted by the natives of India to carry out their works, such, for instance, as the Piccotah pump for raising water where the lift was comparatively little. Pumping apparatus of that description was extensively used in various parts of Europe, for raising water from shallow wells, a balance-weight and force at the end of the lever being substituted for the man who in India raised the water by moving his own weight along the lever.

On the plan of foundations described in the Paper he would offer no opinion further than to say, one great recommendation in its favour was the use of native materials. The construction of the bridges in India really measured the time for the execution of a railway; and consequently there was great advantage in saving delays, by the use of native materials. With reference to the superstructure, he generally gave the preference to solid plate girders for railway bridges. He had not, however, applied them largely in India, because on the Great Indian Peninsula Railway it could only be done conveniently where water carriage enabled the large masses of iron to be conveyed to the site of the work. It was extremely difficult to transport them by the mode of conveyance which the natives were obliged to resort to. He had therefore principally sent out Warren's girders, as they consisted of smaller parts, which, as far as possible, were made in duplicate. An inconvenience of another kind arose with this description of girder, for notwithstanding the utmost care in numbering and packing all the parts, sometimes the marks were obliterated; and at other times parts were lost in transport. He would only add, that he should communicate with the Engineers of the Great

Indian Peninsula Railway, and endeavour to get them to evince their interest in the Institution, by sending to England Papers descriptive of some of the failures of bridges which had been experienced, and of some of the interesting features in the construction of railway works.

Mr. ALFRED GILES said, no one could complain of the cost of these foundations, if, as was stated, the cost of the masonry of this bridge was only £18,000, for a length of 3,000 feet. He was building a large bridge in Austria at the present time; but he was sorry to say, though there was no Board of Works in that country, there was an authority there which would not allow Engineers to follow their own inclinations, and they were thereby often put to considerable additional expense and trouble.

Mr. HAWKSHAW, Past-President, said, with regard to the question relative to plate girders, Engineers, in carrying on works in foreign countries, were often obliged to adopt systems of construction which were not the most scientific. The fact was, the form of girders was sometimes modified by questions of carriage, and, according to his experience, by other considerations; and the consequence was, that scientific views were obliged to give way to other difficulties which had to be contended with in foreign countries. Thus, he knew, that the top and bottom members of a girder need not contain the same sectional area; but in the case of girders sent to Russia, he decided that the sectional areas should be the same, adopting the larger section in both cases, for this reason, that he could not be certain that the Russians would place the girders the right way up; and similar cases might be mentioned even in England. The same thing applied to the question of plate girders and lattice girders. He believed he had used as many of the one kind as the other; but knowing what had happened from former shipments to India, as to the placing of the superstructure together, notwithstanding the careful numbering of the various parts, he had hesitated to send out the open girders. There was great difficulty in making the people understand the integral portions of the structure; they would lose some and misplace others: therefore, though in England he could adopt strictly scientific views, when the work was carried out under his own eye; in foreign countries he was obliged to adopt that plan, which though not strictly the best, was the best suited to the country.

With regard to the question of foundations, he confessed from his connection with India, (having been the consulting Engineer of the Madras and other Companies, for several years), he had become acquainted with many peculiar modes of construction in that country which had excited his admiration. He had not been able to examine these works himself; but he had spent some time in Egypt, where a great many rude mechanical contrivances were in

use; but from what he had learnt of what was done in India, it appeared that the Indians were far superior in these matters to the Egyptians. He hoped that at some future time, Mr. Heppel would prepare a Paper not upon a specific bridge, but upon the general modes of construction adopted in India.

The Madras Railway was one of the lines in India on which the great experiment had been tried of construction without the aid of contractors. The opinion of Engineers generally on this subject was well known to be unfavourable to such an attempt; but the Madras Railway, considering the fact that its length was between 700 miles and 800 miles, had been carried out on this plan with a wonderful amount of success, and as regarded the Chey-Air bridge, for instance, with great economy. He believed this success had been mainly the consequence, in the first place, of the great practical sense and judgment that was brought to bear upon the work, and of the careful consideration which the Managing Director of the Company (Mr. Walker) had, at all times, given to it. For his own part he could hardly imagine anything more novel than the proposal to undertake 800 miles of railway with no contractor for any part of it. It was only fair to state, that though this line was now all but completed, the work (except that there had been a little more trouble in matters of detail than if contractors had been employed) had gone on smoothly and economically. He was happy to bear testimony to the success of this great experiment, which perhaps not many Engineers would have been inclined to undertake, except they knew, and had a high opinion of, the gentlemen with whom they were to be associated.

Sir John Rennie, Past President, said, in the Paper the great points were, the best mode of constructing a bridge across a wide river, divided into two portions, with an accumulation of sand brought down by the currents. There was also the difficulty of bringing materials to the bridge. Before determining the depth to which these foundations should be sunk, it was necessary to ascertain the usual changes of the river; for unless the foundations were sunk below the actual depth of the river which was changing, there could be no security. It was to be presumed that the Engineers who constructed this bridge had taken all the necessary precautions. They employed the means of the country, which seemed well adapted for the purpose, and the result was, after three or four years' experience, that no alterations in the bed of the river had taken place to produce any danger to the foundations. Then came the further question, what was the necessary span of the openings in the superstructure, in order to give the requisite passage to the water during times of flood as well as at low water, and also what

was the necessary span to insure the materials being laid across the piers at the least expense. He thought those questions had been answered satisfactorily. With 70-feet openings, 4 tons weight of each part could be carried by the ordinary means of the country. The materials of the superstructure had been carried along the railway up to the river bank, and then transported from pier to pier in the most economical way possible.

February 14, 1865.

JOHN ROBINSON M'CLEAN, President,
in the Chair.

No. 1,128.—"Giffard's Injector."[1] By JOHN ENGLAND, M. Inst. C.E.

BEFORE entering into the description of this instrument, it may not be uninteresting to glance at what is recorded to have been done by others, for raising or forcing water by means of a jet of steam and apparatus without moving parts.

In 1684, Solomon de Caus, an Engineer and Architect to Louis XIII. of France, raised a jet of hot water by means of a vertical tube which, passing through the top, reached nearly to the bottom of a closed vessel, and the pressure of the steam on the surface of the water therein contained.

In a patent, granted by Charles I., in 1630, to David Ramseye, is claimed, among other things, 'the raising water from low places, mynes and coal-pitts, by fire,' the word steam not being then in use.

In 1663, the Marquis of Worcester, in his "Century of Inventions," describes a way to drive up water by fire, not by drawing or sucking it upwards, but by making vessels, the one to fill after the other, so that the water runs like a constant fountain-stream, 40 feet high. One vessel of water rarified by fire driveth up forty of cold water, and one vessel of water being consumed, by turning two cocks, another vessel begins to force and refill with cold water, and so successively.

This apparatus appears to have been fixed at or below the level of the water to be raised, and, as the Marquis does not seem to have been aware of the effect of steam condensation, must have been very simple; the vessels being filled, their contents were projected upwards by the impulse alone of the steam.

Savery, in 1698, fixed his apparatus about 2 feet below the height representing the pressure of the atmosphere above the level of the water to be raised. The steam which filled his vessel was condensed from the outside; the water which filled the vacuum thus obtained, was further raised by the quantity of motion in steam, as in the system of the Marquis.

[1] The discussion upon this Paper extended over portions of four evenings, but an abstract of the whole is given consecutively.

In 1818, the Marquis de Manoury d'Ectot, who appears to have been the French prototype of the Marquis of Worcester, took out a 'brevet d'invention' for the drawing in and carrying up any fluid by means of a steam jet. In his 'Century of Inventions,' the Sieur Manoury, as he was styled in those republican days, gives a description of an apparatus 'to draw up water from a pit, not only from the depth where it would equilibrate the atmosphere, but from a much greater.' The steam-chamber he fixed at the height to which the water was to be raised; condensation being effected inside this chamber by a jet of water from a contiguous cistern; a column of water, previously supplied from this cistern, would now be sustained at a height due to the atmospheric pressure. At this height the suction-pipe was enlarged by a spherical water-chamber, passing through which, and terminating a little above it, a tube from the cistern conveyed a jet, whose force of projection, converted into pressure, overcame the quiescent force of the column of water which, already supplied from the cistern, filled the continuation of the suction-pipe, whose transversal area gradually increased till its junction with the steam-chamber above. Now, the jet from the cistern, by transmission of its quantity of motion to a proportional quantity of water raised successively from the pit to the water-chamber, by atmospheric pressure, carried that quantity to the steam-chamber which, when filled by this confluence, discharged into the cistern, whence a quantity, equal to that drawn from the pit, flowed to its destination.

It will thus be seen, that when Manoury, by the same means as Savery, had raised water to the height due to atmospheric pressure, instead of, like Savery, carrying it further by means of a steam-jet, he employed a water-jet for raising it to the required height; so that Savery's method, though more than a century older than Manoury's, approaches nearer to that about to be described.

The Mechanism of the Injector.

It is proposed to divide the apparatus into two distinct parts, defined by an imaginary plane passing at right angles to the axis of the instrument, through the space S_1, Plate 11, Fig. 1.

1°. The part above this plane is an adjutage, through which the jet of mixed steam and water is forced by the pressure from the boiler.

2°. That below the plane represents the adjutage which receives the mixture of steam and water for transmission to the boiler.

Of these two parts, the first consists of an inner tube I, sliding in a cylinder O, and dividing it into two chambers, the one S, for the steam, the other, W, for the feed-water. To the cylinder O

is fixed a convergent tube L, which throughout this Paper will be called the 'lance,' within which, but less convergent, the termination of the inner tube I is slid and withdrawn to the extent required, by the handle and screw N, carrying a divided plate. In the inner tube, whose tapering part T is called the tuyère, a solid plug, called the needle, with a tapering termination, increases or diminishes the steam-passage by its less or greater extent of insertion.

The steam from the boiler being admitted to the chamber S, thence passes by holes to the inner tube, whence, by means of the screw N, a slight withdrawal of the needle lets it in to the 'lance.'

In this state of things, the steam-jet would pass through the 'lance' and be lost in the atmosphere; but if the tuyère, by the action of the screw W, be withdrawn from the 'lance,' an annular jet of water from the chamber S will enter the 'lance' and be carried forward or drawn in by the action of the steam-jet from the tuyère, in such wise, that a column made up of steam condensed and non-condensed and liquid water, henceforth called the 'sheaf,' will be formed and projected, in the direction of the axis of the instrument, through the terminus of the 'lance.'

The withdrawal, then, of the inner tube from the 'lance' forms an annular space, determining the quantity of feed-water according to its temperature and the boiler-pressure; the higher the pressure, the greater the opening required; so that, between the point where the tuyère closes the 'lance,' and the opening corresponding to the greatest steam-pressure, is the traverse of this adjutage comprised.

For condensing-engines, a small self-acting valve placed at the orifice of the overflow-pipe, which shuts as soon as the work of injection is established, prevents any air being drawn in by the sheaf into the boiler, and thence into the condenser.

In the axis of the 'lance,' at a short distance from its end, is fixed the second part of the instrument, consisting simply of a divergent tube leading directly to the boiler, and furnished with a valve, which, when the work is stopped, closes with the back-pressure.

The modification introduced into the first part of the apparatus (Fig. 1) is represented in Fig. 2, and has been supplied for a stationary boiler, which, at 60 lbs. per square inch pressure, is of 240 nominal, or 480 actual horse-power.

1°. It will be observed that the tuyère, instead of sliding with the inner tube I, is fixed to the cylinder O, so that it becomes the terminus of the steam-pipe from the boiler.

2°. The inner tube I, instead of carrying the needle, contains the 'lance' L and the divergent tube, and is now, when moved

towards the fixed tuyère, the water adjustment; in this wise, the packing between the water and steam-chambers, which with the moving tuyère was needed, is dispensed with.

Fig. 3 represents a modification of Fig. 2. Whatever be the apparatus used, says the author (M. Turck) of this modification, it is well known that the warmer the water the less the indraught thereof; for, as soon as a partial vacuum is produced, the water thereby vaporises, and as the temperature is increased does vaporisation tend to fill up the vacuum.

The inner tube I in this arrangement isolates the water-chamber. In setting to work, the withdrawal of the needle producing an annular steam passage of only one 50th of an inch wide, the effect of this isolation must be very perceptible, for if, on the contrary, the condensing feed-water comes in contact with the tuyère, some of the steam, passing through a passage so narrow, must be condensed, rendering the in-draught at low pressure liable to suspension.

Moreover, the inner tube I, instead of carrying the 'lance' and the divergent tube, as in the first modification, moves independently of them, as well as of the needle; and thus, not only dispenses with the packing between the water and steam-chambers in the original instrument, but gets rid of packing altogether.

In the original instrument (Fig. 1), should the packing be imperfect, in addition to the contact of the condensing water with the tuyère, not only will the in-draught be difficult to effect, but it will also be difficult to avoid waste of steam at starting, and to vary the feed, while the least change in the steam-pressure, or in the other conditions of working, will throw the apparatus out of gear. In this wise the hesitations or caprices remarked in starting to work the first injectors may be accounted for.

The 'Lance.'

The form of this adjutage has been determined principally by experiment. Theoretically, the section of its orifice should be the same as that of the minimum section of the divergent tube with which it might be merged; but to facilitate the starting to work, they have been separated, and an excess given to the orifice of the 'lance' for the passage of a certain quantity of uncondensed steam or aqueous vapour.

The 'sheaf,' notwithstanding this quantity of aqueous vapour, does not fill this orifice, taking no more than the $\frac{1}{(1\cdot3)^2}$ part, at the maximum feed, and at the minimum feed, does not even fill the entrance of the divergent tube which it passes, in virtue of its inferior density, with a velocity greater than that with which

an opposing column of water would, if unopposed, flow from the boiler.

The minimum section of the divergent tube is the unit by which the other parts of the instrument are measured and proportioned, and determines its power of injection.

Experiments have given 1·3 for the orifice of the 'lance' which is nearly that of the tuyère, nevertheless, at very high pressures this must be reduced to 1·, the tuyère then being 1·2.

The Divergent Tube.

The inventor was of opinion that the form of this adjutage might be modified in many ways, provided always that for a certain length from the minimum section or throat the taper be very slight; but he did not, when he described this part of the instrument, anticipate holding the same opinion, and verifying the same thing, as M. Turck; that no modification of its form, beginning with a length of 60 times and ending with exactly the diameter of the throat, *i. e.*, cutting this tube off close to the throat, has any influence whatever; for M. Giffard's own words were, in speaking of the actual energy of the sheaf, "cette force vive se transforme en travail mécanique dans l'intérieur du tube-divergent;" and, again, he says, "la pression effective du jet va en croissant depuis l'entrée jusqu'au gros diamètre du tube-divergent."

The 'Sheaf.'

Quantity of motion being quantity of matter incorporated with space passed over in unit of time, the 'sheaf' has, for each time-unit the same quantity of motion as the steam-jet had on issuing from the tuyère; since its quantity of motion is the dynamic equivalent of the pressure which produced it.

Let the minimum section of the divergent tube be equal in area to that of the tuyère, from both of which let water issue under the same pressure which ejected the steam; then, each water-jet has the same quantity of motion for each time-unit as the steam-jet, likewise as the 'sheaf' had; and any two of the three liquid-jets, encountering each the other, equilibrate. In other words, if the orifices of the steam and feed-pipes be of the same diameter, and water, under the same pressure which gave the 'sheaf' its force of projection, issues from both of them; then it is as clear that either one of these liquid-jets would, if opposed to, neutralize the 'sheaf,' as it is that the two neutralize one another. But, make the orifice of the tuyère the larger of the two, the steam-jet issuing therefrom being, by condensation, reduced to the section of the smaller, is then, in the same ratio, the stronger; since it has the quantity of

motion due to the larger area of pressure; and, therefore, at any rate with an intermittent action, drives back the water-jet which tends to issue from the throat of the divergent tube.

The indraught of the feed water is accounted for in the same manner as the working of a forge blow-pipe by the direct action of a column of falling water, or the blast in locomotive chimneys, by the abstraction of a quantity of motion due to an instantaneous change in the velocity of the prime mover.

The water having penetrated into the annular space, comprised between the outer surface of the inner tube and the inner surface of the 'lance,' which is determined by their relative positions, mixes with the motive steam, which it partially condenses. From this collision, results a sheaf made up of minute spheres, which, if received into a glass vessel, disappear with the cessation of motion. The spheres are shown by interrupting the 'sheaf,' when issuing from the 'lance,' then, instead of flowing like water in streamlets, it projects particles in every direction which, in certain conditions of light, show that they are, each absolutely, in a state of rotation.

The 'sheaf,' therefore, after the partial condensation of the steam, being composed of spherical particles, is not, on leaving the 'lance,' a jet of liquid water; if it were, its density would be that of water, and its force of projection, calculated from the quantities of water and steam supplied, would be inferior to the quiescent force of the water in the boiler which it has to overcome; but, under the same conditions of orifice and expenditure, experiments prove that its velocity is greatly in excess of that due to water. By admitting a tapering steam-jet to the bottom of a glass funnel of the same taper, it may be seen how the spherical particles are formed in the 'lance,' by its inner surface being brought so near to the outer surface of the inner tube that the mixing of the water with the steam and its partial condensation produce vortices at the origin or springing-line of the 'lance.'

Now, without the tapering of this adjutage, the vortices would produce mere waste of work, but, by turning them into an agglomerate-jet or 'sheaf,' the inventor has obtained onward motion or useful work.

If, therefore, the pressure upon the annular space, formed by the inner tube and the 'lance' be known, it is clear that the steam and water spent may be calculated; the first having less weight and more velocity, the two combined more weight and less velocity, the quantity of motion is undiminished; though the increment of that quantity represented by the acceleration due to the constant pressure be diminished by the momentary vortices; the work of this decrement, if lost for onward motion, is ultimately found in the shape of heat returned to the boiler: the ratio then of water to steam will give the velocity of the 'sheaf,' and its passing the minimum

section of the divergent tube, which is virtually the entrance to the boiler, will be a consequence of certain values of this velocity.

Thus, the only unknown quantity is the pressure between the inner tube and the 'lance,' which is, naturally, function of that of the boiler, the temperature of the feed-water and the annular space by which it meets the steam-jet. This quantity will be, hereafter, determined by the resistance to be overcome.

When leaving the boiler at a temperature due to its pressure the steam escapes from the tuyère, and penetrates a liquid whose temperature is much less, a sudden change takes place—an instantaneous conversion of heat into work. The useful effect resulting from this work is the actual energy or force of projection with which the 'sheaf' in each time-unit is moving: it is the dynamic quantity which will be turned into useful work: *i. e.*, the incorporation of the quantity of motion in with one-half the velocity of the 'sheaf,' or the mass thereof, with one-half the square of its velocity.

With this force of projection, then, the 'sheaf,' after leaving the 'lance' and traversing the space in communication with the atmosphere, encounters the moment it passes the minimum section of the divergent tube the quiescent force of the water in the boiler. The result of the back pressure from the boiler is that the dynamic effect of each successive transversal element being, more or less, according to the quantity of elastic matter held by each, converted into static effect, the sum of these effects represents the total energy of the 'sheaf,' or, in other words, its velocity diminishes, whilst its pressure increases, till it becomes greater than the back-pressure, and injection takes place.

At starting, projected with a velocity greater than that with which a column of water from the boiler tends to flow from the divergent-tube, consequently exerting against this column a superior pressure, the 'sheaf' acts like a water-ram, having, in the space comprised between the orifice of the convergent tube or 'lance,' and the back-pressure valve, energy enough to raise it from its seat. Meanwhile, until the hesitation of the valve to rise, or its vibratory action ceases, and the permanent work is established, a shock is given by the sheaf which, at this moment, has the action of a projectile; it raises the valve intermittently, and this action continues if deprived of its elastic particles without diminishing its velocity; but, if its velocity be reduced to that due to wholly condensed steam, it will not raise the valve.

If, according to the dynamic theory of heat, it be admitted that heat is converted into motive-work, and reciprocally, so that all work, either moving or quiescent, every force, either developed or neutralized by the change of volume or state of bodies, is accompanied by either disappearance or production of equivalent heat,

the quantity of heat spent in the work done by the injector, *i. e.*, the indraught of the feed-water and its injection against the pressure of the boiler, will be, deducting the losses by radiation and contact with the circumambient medium, equivalent to the motive-work.

Now, M. Deloy let into a reservoir containing a given quantity of water, steam from the boiler through the injector with the feed-water cut off. The loss of heat in this operation was not less than that produced by the work of the instrument. The quantity of steam issuing from the tuyère, whence it arrived directly into the reservoir, wherein it was condensed, was less than when it did the work of injecting. This arises from the steam expansion being greater in the first operation than in the second.

Description of Table No. 1.

To preserve the unity which exists in the original, for which the Author is indebted to M. Turck of the Western Railway of France, 1 foot has been taken for the linear unit, 1 cubic foot for the unit of volume or capacity, 1 cubic foot of water at its maximum density for that of weight, 1 cubic foot of water raised 1 degree Fahrenheit for that of heat, and 1 second for that of time. Thus the ratios which represent weight numerically are expressed in their lowest terms, which, incorporated with the number of pounds in a cubic foot according to the temperature of the water, produce quantities expressed by measures in common use.

The calculations are made for a No. 9 injector, *i. e.*, the diameter of the minimum section of the divergent tube, expressed in millimetres.

a_1 represents the area of this minimum section in parts of a square foot.

The column *b* gives in atmospheres the total pressure in the boiler.

The column *c* shows the velocity with which the water in the boiler would, if unopposed, escape by the divergent tube into the atmosphere, deduced from the formula $V = \sqrt{2gh}$; V representing the velocity in feet per second, g the effect of gravity at the end of the first second of fall, and h the height of a column of water which equilibrates the boiler pressure, *i. e.* 33·886 feet for each effective atmosphere.[1]

Column *d* gives the quantity of water which, if unopposed, would be ejected by the divergent tube = a_1 multiplied by the velocity in column *c*, *i. e.*, $a_1 c$.

Column *e* shows the quantity of motion which the water would

[1] These figures are taken to accord with the pressures in atmospheres of M. Regnault's heat-tables.

possess at its ejection, *i. e.*, the quantity $a_1 c$ incorporated with the space c passed through in unit of time $= a_1 c^2$.

By multiplying the figures of this column by the number of pounds in a cubic foot of water, the resistance to be overcome, measured in foot-pounds, is obtained.

In the original, this is expressed by grammètres, which are obtained, owing to the unity of French measures, by merely shifting the decimal point.

Now, taking this quantity $a_1 c^2$ to start with, the sheaf, to enter the boiler, must evidently possess, at least, this force of projection, and its increase of temperature must be minimum to enable it to carry the maximum quantity of water compared with the quantity of steam spent, moreover, its velocity must be minimum, the question, then, arises—what must this velocity be? In addition to the resistance $a_1 c^2$ to be overcome, there is, at starting, that due to the difference of the area of the inside and outside of the back-pressure-valve which is about $\frac{3}{10}$ths, so that there must be $\frac{3}{10}$ths more pressure on the outside, and if the inside pressure is 10 atmospheres, equal to a column of water $10.33 = 330$ feet, there must be on the outside of the valve, a force equal to a column of water 429 feet high to equilibrate the pressure on the inside, and, then, a small additional quantity will raise the valve.

The minimum velocity, therefore, of the sheaf must be that due to a column of water so many times 33 feet as there are effective atmospheres' pressure in the boiler plus $\frac{1}{3}$, instead of $\frac{3}{10}$ths of their height, *i. e.*, the sheaf must possess a quantity of motion $\frac{1}{3}$rd greater than that due to the issue of the water from the boiler; this quantity is f in the Table, and represents the power required.

The quantity of water delivered to the boiler depends upon the area a_1 and the velocity with which the sheaf passes through this minimum section of the divergent tube; but here must be ascertained the quantity of water which the sheaf carries, for, if the 'sheaf' be, on leaving the 'lance,' a jet of liquid water, instead of penetrating into the boiler, it will break up and run to waste.

To insure continuous injection, the quantity of liquid water must be, in its limiting ratio, 2 to 1 of uncondensed steam, which reduces to $\frac{2}{3}$rds of the area a_1 the section a of water in the sheaf when passing through the section a_1.

Dividing, then, the figures of the column f by the numeric value of a, and extracting the square root of the quotient, the velocity of the sheaf is obtained, which is inserted in column g.

Multiplying the section a by this velocity, there is obtained the quantity of water injected, as given in the column h. Under these quantities' natural numbers are their logs., to which annexing the negative characteristic, and adding thereto log 2·529610, the

number of gallons per hour injected is obtained, and at page 211 compared with the results of observation.

Up to the present time the resistance is determined by the column *e*, and the power required by the column *f*: now it becomes essential to ascertain the quantity of steam necessary to give this power, which depends upon its quantity of motion when issuing from the tuyère, *i. e.*, the quantity of water which the steam contains incorporated with its velocity.

This quantity of water held by the steam, or its density, is inserted in the column *i* (note [1]), and the velocity of the steam in the column *k*.

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[1] The figures in this column are derived from the formula,

$$\frac{V}{V_1} = \frac{P_1^{\cdot 955}}{P^{\cdot 955}},$$

in which V_1 represents steam raised from the unit-volume of liquid water to the elastic force $P_1 = 1$ atmosphere (of 14·698 lbs. to the square inch, the decimal parts being taken to accord with M. Regnault's Tables), determined by induction to be very near to 1642·5 units of volume.

Multiplying, then, both members of the above equation by this value of V_1, there results

$$V = \frac{1642 \cdot 5\, P_1^{\cdot 955}}{P^{\cdot 955}}$$

volumes of saturated steam of the various pressures in column *b* of Table No. 1, the reciprocals of which, or

$$\frac{1}{V} = \frac{P^{\cdot 955}}{1641 \cdot 5\, P_1^{\cdot 955}} = \text{Density},$$

$$\text{and log. } D = 3 \cdot 2152409 - \cdot 955 \log P,$$

by which the quantities of water in unit volume of steam at the various pressures are obtained.

The approximation of these quantities to those obtained by the observations of Mr. Fairbairn and Mr. Tate, in the following instances, is, putting density observed as unit,

at	1·7918	atmospheres + 0·0028
	2·8242	,, − 0·0088
	3·7607	,, − 0·0108
	4·0859	,, + 0·0129

The densities given in this column are, according to M. Carvallo, in excess; for the weight of the 'sheaf' injected minus that of the feed-water supplied, gives that of the motive-steam. By experiments it is known that this weight of steam, thus ascertained to be in the 'sheaf,' is less than that which the steam issuing from, with the density due to the pressure in the boiler, would give. By reason of the taper of the tuyère, the depression of the steam therein ought to be, and according to M. Turck, is insignificant.

The question then arises, whether, on quitting the tuyère, expansion of the steam takes place? It is true, that if in the steam taken from and returned to the boiler, the quantity of motion is less than that in the 'sheaf' injected, there is work done that must be accounted for.

When (the annular water-space being adjusted to the pressure of steam) quitting the tuyère before the indraught for feed-water takes place, the jet (of several atmospheres' pressure), encountering simply the resistance of the atmosphere, must expand; but, the 'sheaf' once formed, and the work of injection established, then, on issuing from the tuyère, being instantaneously enveloped by the feed-water, the jet must instantaneously collapse. In this way, after this first condensation takes place, an increase of the actual energy in, or work done by, the steam in

[each

Dividing the power required, or, the figures of column *f*, by the velocity *k* of the steam, the total quantity of water required to be converted into steam to produce this power, inscribed in column *l*, is obtained, and which, divided by the column *i*, *i. e.*, by the quantity of water contained in a cubic foot of steam, gives the column *m*, or the number of cubic feet of steam per second required to inject the parts of a cubic foot of water found in column *h*.

The column *p* (note [1]) shows the quantity of heat in unit-weight of saturated steam at the temperature indicated in column θ.

The column *q* represents the quantity of heat in a cubic foot of steam, and column *r*, the whole quantity spent in the work of injection, which divided by the quantity of water injected from column *h*, produces the increase of temperature in the sheaf, shown in column *s* (note [2]), subtracting which from 212°, the limit of the temperature to which the feed-water can be raised in its

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each successive portion of the jet, may be accounted for as due to the diminution of atmospheric resistance.

Is it true that, in the steam taken from and returned to the boiler, the quantity of motion is less than that in the 'sheaf' injected? The exact measure of the actual velocity, in the one quantity and the other, as well as the weight of each, must be obtained before answering this question and affirming that there is, on quitting the tuyère, expansion, and consequently diminution of density in the steam.

[1] According to M. Regnault, the excess of heat in unit-weight of saturated steam at 212°, its elastic force being then equivalent to the weight of the atmosphere, over the heat of unit-weight of liquid-water at 212°, is represented by 965·7 units.

Hence, the heat taken in by unit-weight while passing from the state of liquid at 32° to that of saturated steam at 212°, is expressed by 965·7 + 180 + (for increased capacity for heat of water at 212°) 0·9 = 1146·6. This sum, called the 'total heat,' diminishes by the constant quantity 305 for each unit of temperature spent or given out; therefore, unit-weight of saturated steam at 212° in passing to 32°, gives out ·305.180, leaving 1146·6—(·305.180) =1091·7 units of heat, insensible to the thermometer, to be given out in passing to the state of liquid water at 32°.

This quantity, then, diminishes as the temperature from 32° increases, but in a slower ratio, and at 212° is reduced to 965·7.

The constant quantity ·305 is a calorific capacity of saturated steam differing from, but in intimate relation with, that of gas of constant volume or at constant pressure.

It is the quantity of heat taken in or given out by saturated steam as its temperature is increased or diminished by one degree, when its state of saturation is maintained by compression. $1146{\cdot}6 + 0{\cdot}305\,(\theta - 212^\circ)$ is the expression by which the figures in column *p*, representing the absolute total heat, are obtained.

[2] To determine the increase of temperature in the 'sheaf,' the escape speed of the motive-steam and the velocity together with the quantity of non-condensed and condensed steam held in the 'sheaf,' must be exactly ascertained: three things which can only be determined within certain limits.

With the same steam-pressure, from a minimum determined by the least quantity, a maximum temperature may be determined by the greatest quantity of steam condensed and non-condensed held by the 'sheaf.'

With a pressure of 9 atmospheres, M. Turck has measured with the centigrade thermometer 122° due to the non-condensed steam enveloped by the 'sheaf.'

Different temperatures are obtained, whilst injecting the same quantity of 'sheaf,' by means of the same quantity of steam, in the same time; for instance:

[1°. Deliver

TABLE No. 1.

[To face page 208.

RESISTANCE.				POWER REQUIRED								HEAT.					
$a_1 = \cdot 0006846$ $a = \cdot 0004564$	WATER IN BOILER.			IN THE SHEAF.			IN STEAM.					Unit-weight of Steam = 1 cube foot of Liquid Water at its maximum density = 62·425 lbs.					
Total Pressure in Atmospheres.	Velocity of Escape to Atmosphere.	Quantity Ejected.	Quantity of Motion.	Quantity of Motion.	Velocity.	Quantity Injected.	Water in Unit-volume of Steam.	Velocity.	Water in Steam.	Total.	Section of Tuyère.	Of Steam.	In Unit-weight of Steam.	In Unit-volume of Steam.	Total Spent.	Increase in the Sheaf.	Maximum for Feed-Water.
b	c	d	e	f	g	h	i	k	l	m	n	θ	p	q	r	s	t
	$h = b - 1$	$= a_1 c$	$= cd$ $= a_1 c^2$	$= e + \frac{e}{3}$	$= \sqrt{\frac{f}{a}}$	$= ga$		$= \sqrt{\frac{c^2}{i}}$	$= \frac{f}{k}$	$= \frac{l}{i}$	$= \frac{m}{k}$			$= pi$	$= qm$	$= \frac{r}{h}$	$= 212^\circ - s$
11	147·7	·10101	14·930	19·906	208·8	·095311 979145	·0060157	1904·0	·0104540	1·7378	·00091267	365°	1193·2	7·1779	12·348	130°·9	81°·1
10	140·1	·09590	13·437	17·916	198·2	·090436 956343	54923	1893·6	94838	1·7267	61235	357	1190·8	6·5404	11·293	124·9	87·1
9	132·1	·09042	11·941	15·921	186·8	·085243 930658	49667	1874·3	84945	1·7113	91253	349	1188·4	5·9033	10·105	118·4	93·6
8	123·5	·08459	10·441	13·921	174·6	·07909 901508	44179	1859·0	74871	1·6958	91167	340	1185·6	5·2378	8·877	111·3	100·7
7	114·4	·07831	8·953	11·937	161 7	·073810 868118	39068	1830·1	65229	1·6695	91223	330	1182·6	4·6203	7·713	104·5	107·5
6	104·4	·07149	7·465	9·953	147·7	·067398 828650	33721	1798·2	55348	1·6414	91275	319	1179·2	3·9759	6·526	96·8	115·2
5	93·4	·06394	5·971	7·961	132·1	·060277 780157	28332	1754·6	45371	1·6014	91267	307	1175·6	3·3305	5·334	88·5	123·5
4	80·9	·05538	4·479	5·970	114·4	·052198 717660	22894	1691.5	35315	1·5425	91247	292	1171·0	2·6809	4·135	79·2	132·8
3	66·0	·04521	2·986	3·981	93·4	·042625 629669	17394	1583·5	25140	1·4458	91270	273	1165·4	2·0264	2·929	68·7	143·3
2	46·7	·03197	1·493	1·991	66·1	·030144 479208	11810	1359·0	14651	1·2406	91293	250	1158·3	1·3689	1·697	56·3	155·7
1·5	33·0	·02261	·747	·996	46·7	·021321 328802	08973	1102·4	09035	1·0069	91340	234	1153·3	1·0348	1·042	50·0	162·0

passage through the injector (note [1]) column t, results, indicating the maximum temperature at which the feed-water can be taken from the tank without breaking up the sheaf and causing it to overflow, instead of entering the boiler.

Injection for Table No. 2.

The quantity injected may be diminished, either by diminishing alone the annular space for the water, the steam-orifice being constant, or by diminishing simultaneously these two openings. The difference of ratio to the maximum injected obtained by these two

1°. Deliver the maximum quantity in a given time with a given pressure to a boiler; the 'sheaf' will get in with a velocity and temperature due to that pressure, as shown in columns q and s.

2°. Diminish the feed-water alone, less water being then acted upon by the steam; the 'sheaf' increases in velocity; but, for each time unit the quantity injected remains the same as previously to the diminution of the water, while the temperature of course increases.

[1] Comparing the figures of this column with those obtained by M. Deloy, by induction from a series of experiments, at which the 'sheaf' breaks up and runs to waste, the following are the results:

8 Atm.	7 Atm.	6 Atm.	5 Atm.	4 Atm.	3 Atm.	2 Atm.
128·5	130·6	132·8	135·5	143·0	149·0	152·6
100·7	107·5	115·2	123·5	132·8	143·3	155·7
−27·8	−23·1	−17·6	−12·0	−10·2	−5·7	+3·1

By which it will be seen that, 1° the calculation fails at 2 atmospheres' pressure; but, from 3 atmospheres there is a margin which widens pretty regularly till 8 atmospheres are reached; and had the observations been extended to higher pressures, this margin would, in all probability, have gone on widening in the same ratio.

2°. By this comparison the same result is arrived at inversely, as that obtained directly from the observations of others, viz., that the temperature of the 'sheaf' increases with the pressure in a slower ratio than that obtained by calculation. On the other hand; the heat taken from, is, saving an insignificant fraction, returned to the boiler; and since "different temperatures are obtained whilst injecting the same quantity of 'sheaf' by means of the same quantity of steam in the same time," considerable indetermination exists in obtaining, by observation, the minimum increase of temperature, *i.e.*, the rise corresponding to the maximum quantity of feed-water injected by a given weight of steam.

As the temperature of steam increases, a greater quantity of heat being given out from the water to produce that increase of temperature, a greater quantity, as compared to steam of lower temperature, is given out insensibly to the thermometer in passing to the state of liquefaction. Let this quantity of heat be 1· at 2 atmospheres' pressure, it would be at 8 atmospheres' pressure of steam 1·12, the relative quantities being $\frac{308}{874} = ·3524$, and $\frac{218}{937} = ·2327$. This consideration will somewhat help to account for the difference between the results of observation and calculation.

One thing, however, is clear, *i.e.*, at the higher pressures the feed-water may be safely taken at the temperatures indicated in this column.

TABLE No. 2.

Name of Company.	Ratio of Section of Tuyère to Throat (or Minimum Section of Divergent Tube).	Feed-water.		3 Atmospheres' Pressure.			5 Atmospheres' Pressure.			7 Atmospheres' Pressure.			9 Atmospheres' Pressure.		
		Height of Induaught.	Temperature.	Maximum Injected.	Limiting Ratio to Maximum by diminishing		Maximum Injected.	Limiting Ratio to Maximum by diminishing		Maximum Injected.	Limiting Ratio to Maximum by diminishing		Maximum Injected.	Limiting Ratio to Maximum by diminishing	
					Water alone.	Water and Steam.		Water alone.	Water and Steam.		Water alone.	Water and Steam.		Water alone.	Water and Steam.
		Feet.		Gallon.			Gallon.			Gallon.			Gallon.		
EST . .	$\frac{113\cdot3}{78\cdot5} = 1\cdot453$	1·5		·2802	0·56	0·25	·2802	0·62	0·32	·2452	0·66	0·65	·3153	0·55	0·11
LYON .	$\frac{124\cdot6}{70\cdot9} = 1\cdot781$	,,	,,	·3105	0·87	,,	·2717	0·35	0·57	·3292	0·94	0·50	·3105	0·75	0·50
OUEST .	$\frac{122\cdot6}{63\cdot6} = 1\cdot947$	,,	63°	·3114	0·23	,,	·3460	0·41	0·30	·3840	0·50	0·35	·3460	0·66	0·44
ATLAS WORKS	$\frac{153\cdot9}{56\cdot7} = 2\cdot749$	,,	54°	·3878	0·56	,,	·4849	0·60	0·40	·4849	0·68	0·40	·3375	0·75	0·43
According to M. Giffard				·2346			·3302			·4034			·4655		
According to Table No. 1				·2405			·3401			·4165			·4810		

operations may be seen in Table 2, in which is given the quantity of water injected per square millemètre of area of throat (or minimum section of divergent tube) per minute, by instruments of four companies, according to experiments made by the 'Compagnie des chemins de fer de l'Ouest.'

Inversely as the pressure of the steam will be the quantity of water injected by a given weight of steam, whereas, nearly directly as the steam pressure will be the quantity of water injected in a given time.

Thus it will be seen, by reference to Table No. 1, that at 11 atmospheres' absolute pressure, the given weight of steam spent injects nearly ten times its weight of water, whereas, at 2 atmospheres, it carries into the boiler more than twenty times its own weight of water.

The quantity injected per square millimètre of the minimum section of the divergent tube, in gallons per hour, will be, according to the Table:—

Total Pressure in Atmospheres.	11	10	9	8	7	6
Gallons.	32·27	30·62	28·86	26·98	24·99	22·81
Log. added to the log. in column h of Table, is 2·529610.	5	4	3	2	1·5	
	20·41	17·67	14·43	10·21	7·22	

These quantities are calculated with an increase of volume from ·1604 to ·1672 parts of a cubic foot in 1 gallon of water raised from 62° to 212°, at which it is supposed to be injected, and compared with the results of experiments made, by the Author of the Table, in litres per minute—

At 9 atmos. there is + ·042 litre per min.
„ 7 „ + ·006 „
„ 5 „ − ·080 „
„ 3 „ − ·177 „

So that at a certain pressure, between 5 and 7 atmospheres, the result would be the same.

Overflow or running to Waste.

That of steam, of course, tells that the supply of water is not adequate to condense enough steam to reduce the sheaf to as small a section as that of the throat of the injector. But that of water may be caused by, 1°. The section of the jet, though the steam be wholly condensed, being larger than that of the throat;

2°. The jet, though no larger in section than the throat, being no longer a compound jet, but, owing to the total condensation of the steam, a simple jet of liquid, condition not permitting without overflow, injection to take place.

Again, without overflow of either water or steam, the ratio of one to the other in the work of injection might be deemed to be properly adjusted; but this is not so; for, from the limiting-ratio of 2 water to 1 steam non-condensed, the quantity of steam held in, may continue to be increased to the limit of, the sheaf being no larger in section than the throat, thus spending more steam than needed.

The ratio, therefore, of water to steam is not correctly adjusted, save in the case when the water supplied is no more than enough to leave $\frac{1}{3}$ section of sheaf to consist of aqueous vapour, and the steam supply is enough, and no more, to leave $\frac{2}{3}$ section of sheaf liquid water. This is of small practical value, however, because the steam unneedfully used is not wasted, but simply taken from, to be returned to, the boiler.

Depth from which Feed-water may be Raised varies as the steam pressure. The excess of power in the sheaf is such that, for 3 or 4 atmospheres' pressure, the injector may be fixed 10 feet below the boiler; in that case, however, the feed-water temperature must be less, and the quantity injected by a given quantity of steam will, of course, be less than if the instrument were fixed level with the boiler. The work established, this depth may be carried about 6 feet lower. And, if the traverse of the steam-needle be extended throughout the 'lance,' this depth may be increased to nearly the equivalent of the atmospheric pressure. The excess of power is likewise such that, provided the ratio between the orifice of the tuyère and the minimum section of the divergent tube be not less than that between the pressure of a receiving and of a generating-boiler, the sheaf may be made to enter a boiler wherein the pressure is greater than that wherein the motive steam is generated.

Injector compared with Pumps.

The test of the Injector appears to be its comparison with an apparatus by which the temperature of the water delivered to a locomotive boiler by means as economical, but other than that of impact of the feed-water with the motive steam, may be raised to the same, or to a higher point than that obtained by the injector.

Now Mr. Beattie's apparatus, about to be described, abstracting its first cost and that of maintenance, is one which, by utilizing the heat of the exhaust steam, fulfils the above condition, by delivering the water at the boiling point, for which he claims a saving of fuel to the amount of $13\frac{1}{2}$ per cent. as compared with

any process other than that of the injector, delivering feed-water at the temperature of 50°.[1]

This apparatus (Plate 12) consists of two pumps A and B; two double side pipes C_1 and D_1 each containing another pipe C and D; a mixing-chamber E, under the foot-plate, connected, by the pipes F and G, with the pumps; a two-way cock and clack-box H, on the left-hand side of the boiler; and a clack K, on the right-hand side of boiler.

The inner side pipes C and D are filled with exhaust steam, of which a part being condensed by the action of the feed-water circulating through the annular space formed by the outer pipes C_1 and D_1, passes, on the right-hand side of the boiler, to the mixing-chamber E, and on the left-hand side, either by the drop-pipe and cock L to E, or, by the pipe M, to the tender.

The cock N regulates the water supply from the tender to the mixing-chamber E, enabling the engine-man to keep therein water at a pumping temperature, say 150°, the limit being 180°.

A cock P, on either side of the boiler, shuts off the exhaust steam either when the tank is sufficiently heated, or to increase the blast when required for raising extra steam when ascending long inclines; but it is not often wanted, owing to the use of a fire-box for coal-burning and smoke-consuming, which does not require a strong blast.

The action of the pump A is constant; drawing water from the chamber E, and forcing it through the two-way cock H into the annular space between the left hand side pipes C_0 C_0 and C C; then across the boiler by the pipe I into the annular space between the right hand side pipes D_1 D_1 and D D; thence by the clack-box K into the boiler, or forcing at once by the clack-box H, by means of the two-way cock in case of accident, into the boiler. The exhaust steam in the inner side pipes C and D is partly condensed, and flows away through the cocks P to the tender. The pump B is only used in case of accident to the pump A.

By referring to column *p*, Table No. 1, it will be seen that 1190·8 units of heat are absorbed in raising water from 32° to saturated steam at 357° or 10 atmospheres' total pressure.

Now, starting with feed-water at 212,° as Mr. Beattie does, to generate steam at 10 atmospheres' pressure, there results $\frac{212 - 50}{1190{\cdot}8 - {\cdot}305\,(50 - 32)} = \frac{162}{1185{\cdot}3}$, and dividing $\frac{1185{\cdot}3}{100}$ and $\frac{262}{11{\cdot}853}$, 13·7 per cent. is obtained, or a fraction more than Mr. Beattie's claim.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xvi., p. 29.

The question then is, what is there to set off against this saving? The heat spent by the working of the feed-pump, except when this work is done by the quantity of motion in the train during the passage of declivities, is an undeniable set off. There is, however, no data for estimating this quantity other than that one volume of steam will equilibrate one of water; the rest is matter of opinion; the mean of the opinions furnished gives 15 units, and dividing $\frac{15}{6 \cdot 5}$, or the heat in unit volume of steam at 10 atmospheres—the result is 2·3. In addition to this the Injector can, at 10 atmospheres' pressure of steam, take feed-water at the temperature t in Table No. 1, *i.e.* 87°[1]; now $87 + 15 - 50 = 52$ to be deducted from the above found 162; dividing $\frac{1185 \cdot 3}{100}$ and $\frac{162 - 52}{11 \cdot 853}$, the result is 9·3 per cent.

The opinion of most locomotive Engineers, both at home and abroad, is, that diminution of the blast-pipe orifice is tantamount to increase of back pressure, and therefore they prefer to regulate the indraught for firing by other means; in this case, however, this orifice is diminished. In a condensing-engine, the "back pressure of condensation," due to the temperature in the condenser, is represented by about 104°, but, here the temperature of the condenser is, initially, that of the mixing-chamber, say 160°, and goes on increasing till it reaches 212°.

As soon then as partial liquefaction of the exhaust steam takes place, vapour is given out, and, as the temperature gradually increases, fills the side pipes with vapour of greater density. In other words, the condensing water being, at starting, very near the limiting temperature of indraught by the feed-pump; the indraught of the exhaust steam—which Mr. Beattie affirms is enough to enable him to reduce the blast-pipe orifice—produced by the difference of its temperature with that of the feed-water, after passing through the pump is inconsiderable and goes on rapidly diminishing till this quantity is represented by $230 - 212 = 18°$.

In this way it is possible to account for the feeling of many engineers, that the resistance, on the whole, is increased; for, when the quantity of air carried by the exhaust steam into, and the friction in, so great a length as the side-pipes of the column of vapour, which takes part of the place of the exhaust steam, are taken into consideration, the margin between the indraught of the exhaust steam, *i. e.*, the diminution of pressure and that due to the atmosphere is narrow.

[1] *i.e.*, if it be worth while to utilize the exhaust steam; for, if it is with pumps, it will be, though in a less degree, with Injectors by using for this purpose a single side-pipe as is done on the South Eastern railway.—J. E.

Moreover, to this apparatus a donkey-engine must be added at a cost of £40, which is greater than that of the injector itself, to feed the boiler, as the injector does, when the engine is stationary.

There are also the greater extent and liability to incrustation of pipes, their wear and tear with that of a suction-valve dispensed with by the use of the injector, the constant friction, and the succession of shocks, at high speeds, of the pump-ram.

To sum up; leaving out the moot point of increase or diminution of back-pressure; the excess of first cost, and that of maintenance, the greater liability to accidents,—for instance, suppose the passage between the ram and the boiler be obstructed, something must give way, whereas, the same obstruction to the working of the injector would merely break up the sheaf and cause an overflow without damage to either pipes or their joints—constitute so considerable if not an entire set off, that most railway companies, both home and foreign, have adopted the injector for all new engines.

Should, however, Mr. Beattie succeed in utilizing, instead of the heat of the exhaust steam, that now wasted in the smoke-box, the simplicity of the machine would be combined with the efficiency he claims for his present method by heating the feed-water after its passage through the injector. This after-heating is now done with stationary boilers. The disadvantages of pumps are still greater when feeding with cold water. Then there has to be considered, the bursting of feed-pipes from the effect of frost, and the unequal expansion of fire-box plates where the water enters, which are obviated by the use of the injector, as well as by a feed-water heater. Moreover, in getting up long acclivities, it becomes needful to have, beforehand, the tank-water heated; in order, when on the incline, the engine-man being compelled to feed to keep up the steam then spent much quicker, to avoid the reduction of pressure; in this case, in the absence of a feed-water heater, the advantage of the injector is manifested by reducing the pressure in a much less degree.

The case, however, in which the injector can be most advantageously compared with pumps, is that of marine-engines, when the ship may have to lay to, or delay her departure from port from unforeseen causes. In an experiment made by Mr. Robinson, of Manchester, on one of the boilers of the 'Great Eastern,' the donkey-engine, by throwing in a given quantity of water, reduced the pressure 10 lbs., whereas the injector, by throwing in the same quantity, reduced the same pressure only 5 lbs. per square inch.

From the low pressure at which marine boilers are usually worked, and from the power of the injector not being diminished by drawing up the feed-water, a high temperature is given to the sheaf without risk of its interruption. This instrument, therefore,

has all the advantages of a donkey-engine with this one in addition, that the motive steam does more useful work by returning to the boiler the heat taken therefrom.

The mode of working with the injector on the Western Railway system of France is, according to M. Turck, as follows: steam is maintained to the indicated pressure of $9\frac{1}{2}$ atmospheres; going down inclines, during stoppages and in the stations, at which care is taken to arrive with low water, the boiler is filled to the maximum water-level; in those stations where the engine must remain some hours before starting, the steam is at 2, or at most 3 atmospheres, and as soon as the engine is shunted, the injectors are set to work to fill the boiler, using up the steam,—which would with pumps and without a donkey-engine be wasted,—to 0. Some engine-men, when the steam blows off, which seldom happens, heat their tender-water, and, by feeding on the declivities and in the stations, save, as compared with the same boilers fed with pumps, but without a donkey-engine, a kilogramme and a half of fuel per kilomètre.

The application of this instrument as an elevator may be made as follows:—

In drainage of mines, where the small coal is burnt to get rid of it.

When steam is blowing off, as in forges at night. This application has been made at the Atlas Works in Manchester—where the blowing off of the steam was formerly a nuisance to the neighbourhood—to fill up the tanks during the night.

Where warm water is of value, as in the case of railway tanks, and in some factories, such as dye-works.

Where the supply is seldom wanted it saves the first cost, maintenance of, and attendance to, a pumping-engine.

Where absolute certainty, above all considerations of cost, is required, as in the keeping of the tuyères of a blast-furnace cool.

When frosts take place, the elevator, like the injector, gets into working order upon the admission of the steam, even when the whole is one mass of ice.

Where the boiler is far off from its work, as in the drainage of collieries, no one need be detached from his work to start or attend to the elevator, for the height to which water is required to be raised being, in this case, nearly constant, after the steam is turned on, the apparatus becomes self-acting, *i.e.*, needs no adjustment of either steam or water supply, as in the case of feeding boilers.

The communication is accompanied by several diagrams, for which the Author has to thank Mr. John Robinson, and from

which Plate 11 has been compiled; also by a drawing from which Plate 12 is made, for which he is indebted to Mr. Beattie.

In conclusion, a list is appended of all that has been published, both at home and in France, on the Injector, in which will be found, saving that which M. Turck has had the goodness to supply, the data for everything given in this Paper:—

"Mémoires des Ingénieurs Civils," 1er trimestre, 1860, p. 57.—"Observations," par M. Ermel. 2e trimestre, 1860, p. 187.—"Analyse du Mémoire de M. Carvallo," par MM. Brüll et Ermel.

"Théorie," par M. Reech. Paris, 1860.

"Notice théorique et pratique," par M. Giffard, 2e édition. Paris, 1861.

"Annales des Mines," 5e série, tome xv., p. 169.—Note, par M. Combes.

5e série, tome xvii., p. 301, Notice et Expériences, par M. Deloy.

P. 321, Discussion d'une Notice, par M. Giffard, par M. Combes.

P. 357.—Résultats des expériences, par M. Villiers.

6e série, tome i., p. 575.—Recherches théoriques, par M. Résal.

P. 606, Recherches expérimentales, par MM. Minary et Résal.

6e série, tome iv., p. 517, Injecteur perfectionné, par M. Turck.

"Trans. Brit. Assoc.," vol. xxx., p. 39, On Giff. Ing., by William Froude.

"Proc. Inst. M. E., at Birmingham," vol. ix., p. 39.—On Giff. Ing., by John Robinson.

P. 74, Supplementary Paper, Vol. x., p. 220.—Injector as Elevator, by Charles Wardle.

[Mr. John Robinson

Mr. JOHN ROBINSON said, he had not had an opportunity of going through the calculations given in the Paper, or of testing the conclusions which had been arrived at. There seemed, however, to be some errors, possibly they might be only apparent ones, which the Author would be able to explain; but there was one statement, with reference to the temperature of the feed-water, which was manifestly a mistake; because it was found that the temperature of the feed-water at the steam pressure of 30 lbs. on the inch might be 140°, and since, as the pressure of the steam was increased, that of the feed or supply water must be diminished, in a locomotive working at high pressures, it would not be safe to take water at a higher temperature than 100° Faht. Therefore, when it was suggested to heat the water in the tender by the steam otherwise blown off, the engine-driver must be careful not to carry that heat to more than 100° Faht., as if higher, the action of the instrument would be uncertain. He was glad to find it stated, that the quantity of water delivered by the Injectors manufactured in England was greater than by any manufactured in France. The quantity was much greater than that which was arrived at, theoretically, either by using M. Giffard's formula, or that of M. Turck. The chief object of the latter, in his arrangement, seemed to be, to guard the steam in the tuyère from the condensing effect of the supply-water surrounding the tuyère.

Mr. Robinson was certainly surprised at the theory propounded in the Paper; because all the experiments that had come under his notice, as to the action of the Injector, proved that the denser the jet,—whether of steam, or of mixed steam and water,—after passing the interval of space exposed to the atmosphere, the more perfect the work of the Injector; *i.e.*, the greater was the quantity of water injected into the boiler. In proof of this he stated, with regard to the adjustment of the annular space of the tuyère by the steam needle, that if this were done so as to suppress all overflow, and this space was then further reduced, thus diminishing the quantity of steam supplied to the Injector, it increased the delivery without other adjustment, which showed that the more perfect the condensation of the steam passing this interval, the greater the amount of work done by the Injector itself.

In reply to an inquiry as to whether there were any instances in which the Injector had been substituted for the feed-pump, Mr. Robinson stated that all the new engines on the London and North Western Railway were made to depend entirely upon the Injector for the feed-water, and there were no pumps to the boilers. The application of the Injector to locomotive boilers was more difficult to manage than in the case of stationary boilers, in consequence of the undulations of the road and of the shocks from contact with waggons; but now that difficulty was overcome, and

Fig 2

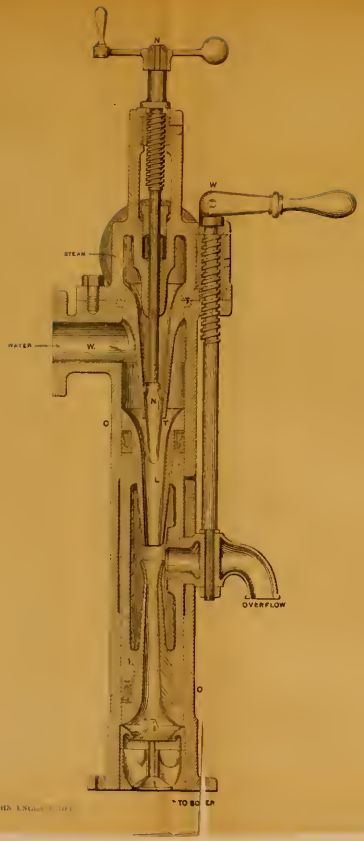


Fig 3.

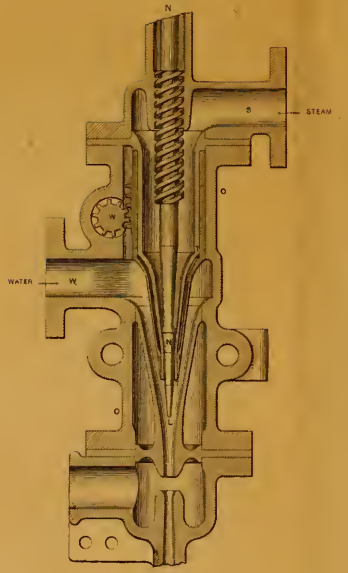


Fig 1

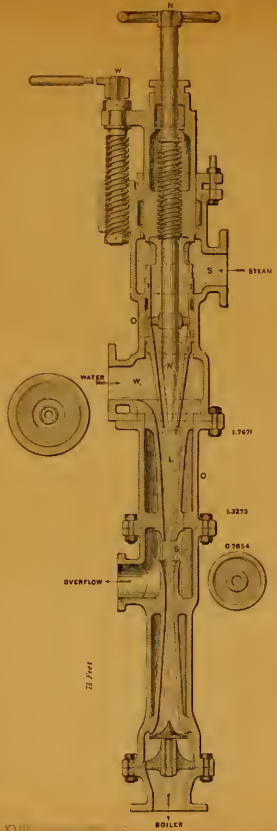
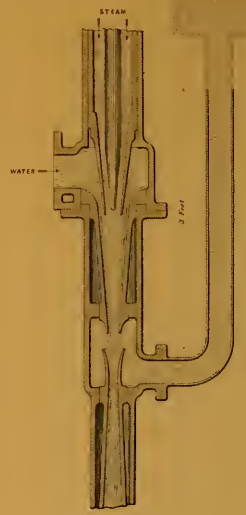
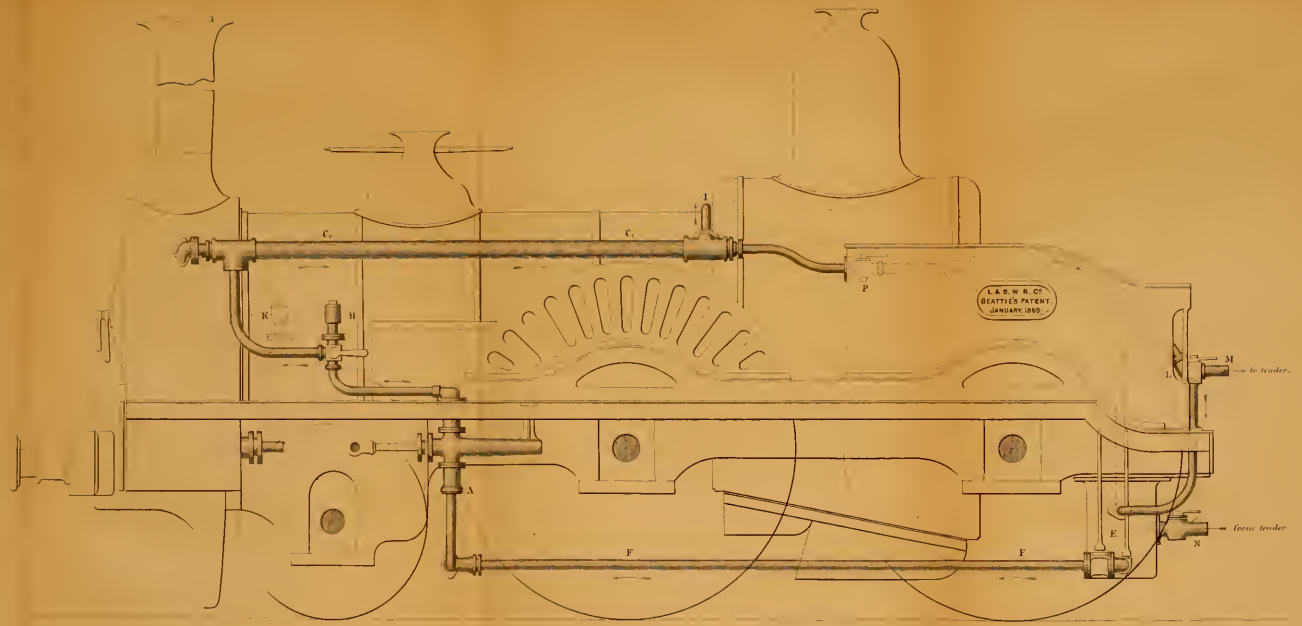


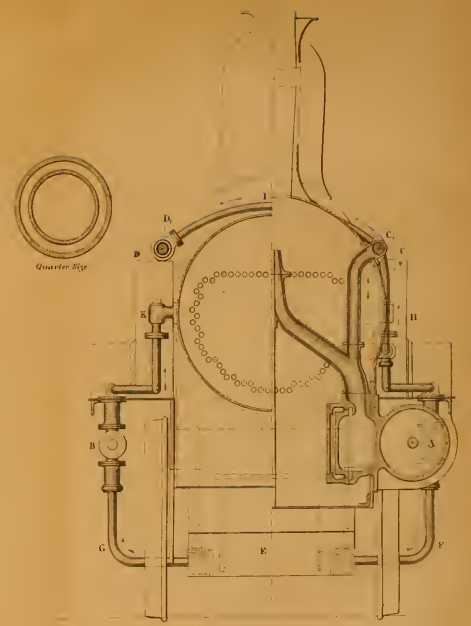
Fig 4.



KELL BROS LITH^rs CASTLE ST. HOLBORN

FEED WATER HEATING APPARATUS.





he had no hesitation in recommending the application of the Injector to locomotive and all other boilers, without the addition of a pump.

Mr. BRAMWELL remarked, that he had had the subject of the Injector under his consideration, more or less, for the last five years, and the statement in the Paper, that if the steam were entirely condensed, so that the sheaf was composed of 'solid' water, it would not enter the boiler, and that in order to do so it was necessary one-third of the contents of the sheaf should be uncondensed steam, certainly came upon him by surprise. Now, it might fairly be said, that the whole of the calculations in the table referred to in the Paper were based on this theory, that one-third, by volume, of all the contents of the sheaf must be uncondensed steam; and that if so much water were combined with the issuing jet as to condense the whole of the steam the mass constituting the sheaf would not enter the boiler, but would break up. That was a theory of the action of the Injector entirely opposed to the results of experience; and yet, (notwithstanding that upon its correctness or non-correctness every calculation in the Paper depended,) beyond the bare statement that it was necessary one-third the contents of the sheaf must be uncondensed, no reason was given, or practice recorded, to justify such a theory.

Mr. THORMAN had had an Injector in use for about fifteen months, and, during that period, he believed it had been taken down fifty times. Many plans had been tried to make it answer, but as yet without success. It could not be depended upon for a week together, and sometimes it went wrong two or three times a day. It might be that the water in the tank was heated to too high a temperature, in consequence of repeated trials to get it to work, otherwise he was at a loss to account for its non-success in this case. Under these circumstances, he could not rely upon an Injector alone.

Mr. G. H. PHIPPS thought it was desirable, upon the present occasion, to examine rather into the general principles of the Injector, than into those more minute points, which could only be ascertained by considerable study. The first impression in most cases, with regard to the invention, would probably be a doubt as to whether the Injector would act at all. It seemed unlikely, at first sight, that by taking steam, by means of a pipe, out of a boiler, and causing it to act upon water at rest, it should be capable of forcing that water back again into the boiler against the steam pressure. There also appeared, at first, an absence of the consumption of power necessary for the accomplishment of any mechanical object; but further consideration removed these impressions, as he hoped to be able to show. He thought the action of the Injector served to explain a much-discussed point in hydraulics, the

effect of a jet of water upon any plane surface upon which it might impinge, as compared with the pressure of the column of water in the vessel from whence the jet proceeded. In all the leading works on hydraulics, it was fully demonstrated, that the force of impact of any jet of water must be double the pressure due to the column producing the jet. Separating, for the moment, the Injector from all the difficult considerations as to heat, if the pressure of steam on the surface of the water were regarded as so much additional column of water expressed in feet, and the boiler as a reservoir subject to this charge, every square inch of the interior of which was pushed outwards with a corresponding force, then the jet being established, and brought to bear against any surface of the exterior of the boiler, equal in area to the 'vena contracta' of the jet, a pressure double that of the outward pressure would supervene, and if a valve, opening inwards, were placed there, the fluid would enter with a velocity due to the square root of the difference of pressure, similarly to what took place through an aperture in a partition dividing a reservoir, where the water stood at different levels on each side. It might, perhaps, be urged, in opposition to the above view, that the double force given out by impact only existed so long as the surface receiving it remained stationary. Admitting this, however, Mr. Phipps was still of opinion, that the action against the water within, commencing at first with the full amount of force, did not cease so long as there was any balance of pressure in favour of the jet, when the whole column within the reservoir came to be in train, similarly to the laminæ of a fountain directed perpendicularly upwards. Although he could not refer to any experiment, where the jet of water issuing from a reservoir had been made to enter another reservoir equally full, he thought it would be useful to advert to some experiments by Professor Magnus,[1] from which it appeared that a jet of water 3 millimètres diameter, with a velocity due to a head somewhat exceeding 7 feet, entering a vessel by means of a glass tube 12 millimètres diameter and 6 inches long, sustained a head of 10 inches in the vessel, without the escape of a single drop from the aperture in the glass tube, although 4 times the diameter, or 16 times the area, of the jet. Thus, 10 inches, being the height of the head supported, × 16, the ratio of the tube to the jet, would be equal to a head of 160 inches acting upon the area of the jet, or about double that from which the jet originated.

If the above reasoning were correct, the action of Giffard's Injector could be easily calculated. The speed of passage of water through the narrowest part of the divergent tube would be that due to a column of water having the same pressure as the

[1] Phil. Mag., 4th Series, vol. i., page 1

steam in the boiler, and this multiplied into the area of the section would of course give the quantity in any given time. In confirmation of the applicability of this method Mr. Phipps had calculated the speed through the tuyère due to 50 lbs. pressure of steam on the square inch in a boiler, and found it to be 28·5 yards per second, whilst the actual result of an experiment, recorded in a most interesting Paper by Mr. John Robinson,[1] calculated for 4 millimètres the diameter of the tube, gave 26·5 yards;—an approximation perhaps as near as could be expected, when no allowance had been made, in his calculation, for friction, or other drawbacks.

He had calculated one of the experiments given in Mr. Robinson's Paper by the following formula:—

Calling P, the pressure of the steam in a boiler, and V, the theoretical velocity through the tuyère in feet per second, the velocity through the divergent tube would be

$$V = 8 \sqrt{P}\ \overline{2 \cdot 24}.$$

The actual speed, in the case previously given, came out at $\frac{13}{14}$ths of the above.

In order to test the accuracy of this method, Mr. Phipps had examined the results of other pressures of steam given in the Paper already alluded to, from which the following Table, showing the quantity of water in gallons per hour which a No. 4 injector (diameter of divergent tube 4 millimètres = 0·16 inch) was capable of delivering at various steam pressures, the temperature of the feed-water being 95° Faht., was extracted:—

TABLE II.

Quantity of Water delivered at different Pressures of Steam.

Pressure of Steam, lbs. per square inch .	5	10	20	30	40	50	60
Water delivered, gallons per hour . .	93	124	150	186	210	244	259
These quantities become when multiplied by 1·4, the ratio of $\sqrt{1}$ to $\sqrt{2}$ . .	..	130	174	..	210	..	260

Neglecting the two experiments where the pressure of steam was only 5 lbs., and 10 lbs., where probably the temperature of the feed-water was too low to develop a perfect action of the injector, all the others, viz., 20 lbs. and 40 lbs., 30 lbs. and 60 lbs., the water delivered would be found to increase precisely as the square roots of the steam pressures.

Apart, therefore, from the more refined considerations of quan-

[1] Institution of Mechanical Engineers, Proceedings, 1860, pp. 39–51, and pp. 74–82.

tity of heat, vis viva, &c., the above method would furnish the practical engineer with a simple rule for determining the quantity of feed-water capable of being sent into a boiler by an Injector of given diameter of divergent tube, under varying pressures of steam.

One of the most singular phenomena connected with the Injector was, that not only could it be employed for causing feed-water to pass into a boiler, by using the steam from the same boiler, say at 50 lbs. to the inch, but the Injector could also be made to work from a boiler with 40 lbs. into another boiler where the pressure was 50 lbs. on the inch. According to his method of calculation the limit to this would be when the lower pressure was just one half of the higher; because by considering the force of the impact due to the lower pressure to be equal to double the height of the column, this pressure would just equal the higher pressure. At this point all feed would cease; but at all pressures between one half, and the whole, feed would be supplied in the proportion of the square roots of the difference of twice the lower steam pressure to once that in the boiler to be supplied.

Sir William Armstrong, C.B., observed, in reference to what had been said on the much-vexed question of the force of impact of the jet from a given height, that it would almost appear to involve the principle of perpetual motion; for supposing a pipe of proper form to be attached to the foot of one of two divisions of a cistern, so as to produce a jet, operating under the most favourable conditions, against an orifice in the other division, then, according to this theory, the pressure in the column in the one division ought to be sufficient to carry the jet into the other division, in which case the water would flow over the partition, and circulate in perpetual motion.

Mr. Phipps said, in explanation, that he assumed two vessels to be each full to the same extent, with a jet from the one directed against a valve opposite to it in the other, for the water to enter by. Assuming the nozzle to be turned upwards, instead of being directed against the opposite vessel, theoretically every particle of the fluid thrown out would go to the height of the surface of the reservoir; so that they would have rapid motion of the fluid near the bottom of the reservoir, gradually coming to nothing at the surface. But this was not the "perpetual motion" abjured by all sound mechanics, which he took to be, the attempt to do a certain amount of work at one end of an assemblage of mechanical parts, without the supply of the corresponding consumption of power at the other end. All motion must necessarily be theoretically perpetual. Once set a-going, a pendulum would swing for ever, were it not for the resistance of friction and of the atmosphere.

Mr. C. W. Siemens thought that the cause of action of this instrument should be better understood than it appeared to be, on

account of the physical principles involved, which were, without necessity, at present invested with mystery. He could not agree in the view, expressed by Mr. Phipps, that the action of the Injector was due to the circumstance, that the impact produced by a jet on a solid surface was equal to double the pressure due to the area which produced it; but he thought it might be shown, that the jet produced by the steam possessed a very much higher velocity than a jet of water produced by the same pressure which would come out to meet it from the boiler. Thus the steam from the boiler issued with a velocity $v = 8\sqrt{h}$, or nearly so, neglecting the error arising from the circumstance of its being an elastic fluid; while the water of the boiler would issue with a velocity represented also by the formula $v' = 8\sqrt{h'}$; but the pressure being the same in the two cases, it followed that the height of the column h was superior to h' in the proportion of the relative densities of steam and water. Hence the velocity v of the steam would exceed the velocity v' of the water in the proportion of $\sqrt{h} : \sqrt{h'}$, or in the case of steam of four atmospheres' pressure, $v : v' = \sqrt{1} : \sqrt{477}$, water being 477 times denser than steam of that pressure, or $v : v' = 1 : 21{\cdot}8$.

It was therefore evident, that every particle of steam rushed forward with a velocity nearly twenty-two times greater than that with which the water could meet it, only if it were to rush forward in its elastic state, it was evident that each particle of steam would have to encounter 477 particles of water within the same volume, and must be forced back notwithstanding its superior velocity.

But if the steam were imagined to be condensed between the point of issue and that of its meeting with the jet of water, if, for instance, its elastic force could be destroyed by making it pass through an infinitely cold space, then the result would be a very contracted jet of water passing forward with the extraordinary velocity of $v' = 8\sqrt{h'} = 8\sqrt{477 \times 3{\cdot}32} = 1712$ ft. per second, meeting a column of $v = 8\sqrt{h} = 8\sqrt{3{\cdot}32} = 78$ feet per second.

The effect would be, that the column of water resulting from the condensation of the steam would pierce the comparatively sluggish jet of water meeting it, as though it were a steel wire forcing its way into the boiler. This was, however, an impossible position, for the steam could not be condensed by itself spontaneously. But the Injector effected the spontaneous condensation of the jet of steam by incorporating with it a sufficient quantity of cold water, which was so regulated, that the mean velocity of the united jet of steam and water still exceeded the velocity of 78 feet per second with which the opposing jet from the boiler would meet it. Supposing the initial temperature of the water to be about 70°

Faht., the weight of the condensing water should exceed the weight of the condensed steam about ten times to effect perfect condensation; the velocity of the united jet or sheaf would be in this case $= \frac{1,712}{10+1} = 155$ feet per second, or nearly doubly sufficient to force its way into the boiler.

It might here be remarked, that the Author of the Paper was clearly in error when he stated that the steam was only partially condensed in the sheaf. Uncondensed steam encountering water could not drive it back; but a column of water encountering another column of inferior velocity must drive it back. It was essential that water of sufficiently low temperature must be brought into contact with the jet of steam to effect its entire condensation, without reducing its velocity below the limit indicated by the imaginary velocity of the opposing column. In the case assumed the weight of condensing water, or of the water injected into the boiler, must not exceed the weight of condensed steam by $\frac{1,712}{78}$ = 22 times, or making allowance for losses of effect, say by 18 times. Taking the total heat of steam at 1,150 units, it followed that the rise of temperature of the injected water would be $= \frac{1,150}{18} - 64°$ Faht., and assuming that the final temperature of the sheaf must not exceed 190°, in order to effect entire condensation, it followed that the initial temperature of the injected water must not exceed $190 - 64 = 126°$ Faht. If it should be attempted, under the circumstances, to inject water of a temperature exceeding 126° Faht., the sheaf must break up, and the action of the instrument be paralyzed. On the other hand, the greatest quantity of water which each pound of steam would be able to take depended upon the relative velocity of steam and water when acted upon by the same pressure, and might be expressed by $\frac{1,712}{78} = 22$ lbs. That would be the greatest quantity of water which each pound of steam could urge forward into the boiler, or could urge forward if there were no loss from friction or by the vortices formed. In reality it would probably not deliver much above half that quantity into the boiler.

The subject had been considered irrespective of the question of heat, but that, in his opinion, was a fallacious method, for, it would be seen, that without complete condensation the instrument could not act; neither could its effect, nor the limits of its action, be determined, without taking into account the amount of heat contained in the steam and in the water, as well as their proper velocities when acted upon by pressure.

Mr. Siemens thought the Injector could only be advantageously applied as a motor, in cases where the water had not only to be raised but also to be heated, and its legitimate application would probably remain confined to the feeding of steam boilers. Its practical advantages were not overstated in the Paper, where feed-water of sufficiently low temperature was used. The minimum temperature, to obtain an advantageous result, would be about 100° Fahr. In the case of a high-pressure engine, it was a question whether a heater and a pump would not be more advantageous than this instrument. The Author had stated that 2·3 cubic feet of steam would be expended to pump 1 cubic foot of water into the boiler. But even this calculation, unfavourable as it might seem, still left a great margin in favour of the pump, inasmuch as the water could be raised by waste heat to nearly 212°. He believed that the Injector would be found applicable with the greatest advantage in the case of marine engines, or of condensing engines in general, where there were no means of heating the feed-water to above 100°. Under such circumstances the power expended to work the feed-pump could be entirely saved, because although the Injector would expend heat on the water, it would return the same to the boiler; whereas the pump used the steam to work it, and gave nothing in return.

Mr. PHIPPS was misunderstood if it was imagined that he thought heat had nothing to do with the proper explanation of the action of this instrument. What he meant to say was, given that condition of the Injector in which it worked most favourably, without inquiring what must be the ratio of the quantity of steam used to that of the water, to furnish a practical and easy method of finding what the velocity through the small pipe, or tuyère, would be with a given pressure of steam? He never affected to try to determine what ought to be the relation between the quantity of steam and the quantity of water; but having given the size of the tube, and the pressure of steam in the boiler, to indicate how many gallons of water could be sent into the boiler in a given time.

Mr. ROBINSON directed attention to a point which appeared to have been lost sight of, to a considerable extent, the difference of area of the various passages adopted by M. Giffard. The net area of the tuyère, without deduction for the needle which would be drawn back, was considerably in excess of the area of the receiving nozzle of the divergent tube, the proportion being—

Area of the tuyère	1·7671
Area of the combined nozzle . . .	1·3273
Area of the receiving nozzle, or divergent tube	·07854

Since his attention had been drawn to this branch of the subject,

he had tried many experiments to ascertain what the proportion of the passages had to do with the efficiency of the Injector. For that purpose he had an instrument made, in which the diameter of the tuyère was equal to that of the receiving nozzle. The result, under those conditions, was that he could get no action of the Injector at all. The valve which shut off the boiler seemed in equilibrium, and rose and fell according to the dryness of the steam in the boiler. He then increased the passage of the tuyère from 1 to 1·1 of the receiving nozzle, when the Injector worked very satisfactorily, with steam of 50 lbs. into a boiler with steam of 60 lbs. By calculation it should have worked with steam of 49 lbs. into a boiler with steam of 61 lbs., so that it seemed to bear out the idea which M. Giffard had adopted, in proportioning the area of the tuyère to that of the receiving nozzle of the divergent tube.

Mr. Henry Maudslay could not agree in the advisability of dispensing with the feed-pumps, and of substituting the Injector, particularly in marine engines. Soon after the introduction of this instrument, an Injector was applied to a tubular boiler, in his manufactory, working with a pressure of from 15 lbs. to 20 lbs. per square inch. In this case it did not answer; and although the late Mr. Field, and their late manager Mr. Sherriffs, paid great attention to the subject, they failed to arrive at a satisfactory result. At first the instrument drew the water from the hot well of the engine, at a distance of about 50 feet, and a little below the level of the Injector. With this arrangement the action of the instrument was most uncertain, rarely continuing for above a few minutes without stopping. A small cistern was afterwards placed just below the Injector, with the pipe leading from the hot well into it. The action of the instrument was thus rendered more certain, but it still required so much attention on the part of the engine-man, that after a trial of eight weeks it was removed. It was then fixed to a boiler working with a pressure of from 50 lbs. to 60 lbs. per square inch. In this position it acted admirably, and had continued at work ever since, without giving the least trouble. From his experience, he was certainly of opinion, that the Injector was more fickle in its action at low pressures than at high pressures, and was more easily stopped by any external disturbing force. It had been stated, that if the water was above a certain temperature, the Injector would not act. In Canada, he had found that the feed-water might be too cold. Further information on this point was, he thought, necessary. He should not like, in any case, to take the responsibility of recommending, that the feed-pumps and the donkey-engine in steam-vessels should be removed, and reliance be entirely placed on the Injector. The feed-pumps were sure in their action, and were thoroughly understood by the men in charge; whilst the Injector was, and was

likely to be for some time, an instrument of which the great majority of the engineers on board steam-vessels could have but little experience. He considered that the fatal objection to its universal adoption was its uncertain action during rough weather, in consequence of the fluctuation of the level of the water in the boiler, and in the long ranges of suction and feed-pipes, which, in large vessels, might perhaps be from 100 feet to 120 feet long. It would be readily understood, that one end of these pipes might be at one moment several feet above the other end, while in another minute these conditions might be reversed. This could not fail to interfere considerably with the perfect and regular action of the instrument, even if it did not stop its action altogether, which Mr. Maudslay was inclined to think would perhaps frequently happen. At times then, when perhaps the safety of the vessel and the crew depended upon the certain action of the machinery, it might be found almost impossible to get the proper supply of water into the boilers. The donkey and auxiliary engines were applied to other purposes than filling the boilers; and as they were considered an auxiliary in case of any accident happening to the feed-pumps, he protested against their being replaced by the Injector, for they might be called into requisition under circumstances in which he believed the Injector would entirely fail. It should also be remembered, that in marine boilers it was at times necessary to supply a much greater quantity of water than was required for the generation of the steam, so that the accumulation of salt and earthy matters might be blown out, through the blow-off cocks. The composition of sea water varied considerably in different parts of the world; the chemical constituents of the waters of the Red Sea, for instance, being very different to those of the Atlantic. This would render the action of the instrument uncertain at sea, in consequence of the priming, caused by any difference in the quality of the feed-water; especially when a vessel, after being at sea, entered into fresh water, or, on the entering, or leaving a river, with the boilers filled with dirty fresh water, changing to sea water. It was well known that, under these circumstances, considerable priming took place, which would render the action of the Injector uncertain, at a time when a larger supply of water would be necessary. Therefore, without passing any opinion as to the value of the Injector as compared with feed-pumps, or with the feed arrangement proposed by Mr. Beattie for locomotives, he did not think the instrument had as yet been brought to such a state of perfection, that the ordinary feed-pumps could with safety in all cases be dispensed with, and Giffard's Injector be substituted for marine engines. The safer conclusion, at present, he thought would be, that under all circumstances in marine engineering, the feed-pumps should

certainly be retained, while the Injector might perhaps be added with advantage.

Mr. F. J. Bramwell said, when this subject was first brought under his notice, it was a matter so strange, that it was natural any one to whom it was mentioned should desire to endeavour to understand it. Many persons to whom the result of the invention was then communicated said the statement of its performance was impossible and absurd. Such was the condition of the engineering mind at that time.

Many theories had been started as to the principles on which this instrument acted. But before considering the theory he would refer to an experiment he had recently made. The apparatus for the purpose consisted of a cistern, provided with a jet near the bottom, and having an overflow-pipe to keep a steady head of water; that head being 4 feet above the level of the jet. The jet was intended to be $\frac{1}{8}$ of an inch diameter of bore, but it was actually $\frac{7}{48}$ths. It was endeavoured to make this jet of the form of the 'vena contracta,' and in order to ascertain how nearly the true shape had been arrived at, the time required for a given weight of water to issue was observed; it was then found, that whereas, by calculation, taking the absolute flow at eight times the square root of the head $2\frac{1}{2}$ lbs. ought to issue in $22\frac{1}{2}$ seconds, that quantity issued in $24\frac{1}{2}$ seconds. From this it appeared that the rate of flow was $\frac{11}{12}$ths of that which it should be by calculation. Opposite to the jet there was an elbow containing a receiving orifice, or adjutage, about $\frac{3}{16}$ths of an inch diameter. To the vertical limb of the elbow was fixed an upright glass tube, and to the elbow was attached a cock, by which the contents of the tube could be allowed to run away. There was also a box with glass sides, enclosing the jet, to collect the water from the recoil, while at the same time it admitted of the jet being seen. The cock of the stand-pipe being shut, the jet was allowed to flow, and to force the water into that pipe, and it was found that the maximum height to which the water was injected in the tube, and held there, was 3 feet 5 inches to 3 feet $5\frac{1}{2}$ inches; and at that point every drop recoiled from the receiving tube, was caught by the box, and conveyed away by its waste-pipe. This was the first experiment, and was merely to ascertain the maximum height to which the water could be forced in the tube, when the whole of the issuing water was allowed to recoil. In the second experiment the cock in the stand-pipe was opened so far that the water was maintained in it at only 1 foot above the jet, and was maintained quite steadily at that height. It was then found, with this 1 foot head, that 90 per cent. of all the water that was delivered by the jet went into the tube, and only 10 per cent. recoiled and came away. The third experiment was to regulate the cock in the stand-pipe to

preserve 2 feet head, at which 60 per cent. of the water went into the tube, and 40 per cent. came away. In the fourth experiment, when 3 feet head was maintained, 40 per cent. of the water went into the tube and 60 per cent. came away ; while, as before stated, with a head of 3 feet 5 inches none went into the tube, but all recoiled. The first head, of 1 foot only, gave a useful effect of $22\frac{1}{2}$ per cent. ; the 2 feet head 30 per cent. ; and the 3 feet 30 per cent. ; so that about one-third of the whole might be taken as the useful effect to be got out of a jet of that kind.

It was stated in Tredgold's 'Tracts on Hydraulics,'[1] that the useful effect of impact of water on wheels, as the mean of a number of observations, was exactly $\frac{3}{10}$ths of the whole effect, which agreed with the result obtained at these two heights of 2 feet and 3 feet head.

These experiments might possibly have some interest for the members, although not of any great value, as tending to useful results. He had been induced to make them, partly in consequence of some views stated in the course of this discussion, and partly because he had long wished to try, whether an adjutage could be made of such form and dimensions in relation to the jet, that by the expenditure of a large percentage of water in recoil, some small percentage might be raised to a greater height than that of the head producing the jet. He was led to hope this from a consideration of two facts : the first was, that a wave having a rise and fall of 7 feet or 8 feet at the mouth of a river, or inlet, occasionally caused a rise and fall of 20 feet or 30 feet at the upper end. This no doubt was due to the accumulated work in that wave, and he had hoped to make use of the accumulated work in the jet to raise a portion of it to a greater height than that from which the water had fallen, as was done in the hydraulic ram (the second fact he had in mind), in which a small portion of water went to a greater height than the whole came from.

He had endeavoured to devise an apparatus which might be looked upon as a continuous instead of an intermittent ram, but in this attempt he had been disappointed. He trusted it would be understood that he did not expect to get anything in the nature of perpetual motion. All that he looked for was, to so use the accumulated work, as to raise a portion only of the water to a greater height than that which produced the jet. It had been stated on a previous evening that the whole body of the jet might be got into the opposing vessel,—not certainly to the full height, but to within $\frac{1}{8}$ of an inch of that height. That appeared to involve a paradox nearly as great as that of perpetual motion itself, but had now been withdrawn. He had tried with a difference be-

[1] 'Tracts on Hydraulics,' etc. 8vo. London, 1836. Page 12.

tween the two heads of 4 to 1, when only 10 per cent. recoiled, so that he thought it extremely probable that with a difference of 7 to 1, the whole of the water would be received, and none would recoil, as was now said to be the case.[1]

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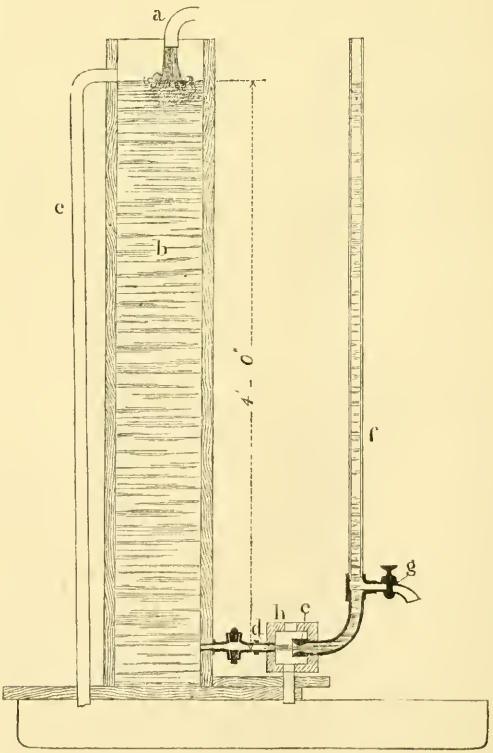
[1] This jet apparatus was subsequently improved, by using new jets and adjutages, carefully prepared in gun metal, in lieu of those roughly made in lead, which, to save time, were employed in the before-mentioned experiments. The results with these better-finished jets far exceeded those obtained at first The apparatus (Fig. 1) consisted of—*a*, supply pipe, *b*, cistern for jet, *c*, overflow, *d*, jet, *e*, adjutage, *f*, stand pipe, or opposing head, *g*, cock to regulate height of opposing head, and *h*, box with glass sides round jet.

Fig. 1.



The head to produce the flow was, in all cases, 4 feet.

1st experiment, without adjutage, merely to ascertain how nearly the actual flow from the jet agreed with the theoretical flow.

The orifice of the jet was $\frac{1}{8}$th of an inch diameter =, in area, $\frac{1}{4582}$ square foot. The velocity was $8\sqrt{4} = 16$ feet per second, $= 286\frac{3}{8}$ seconds to discharge 1 cubic foot. Then 1 quart, or $2\frac{1}{2}$ lbs. $= \frac{1}{25}$ cubic foot $= 11{\cdot}45$ seconds to discharge $2\frac{1}{2}$ lbs. The actual time was $11{\cdot}54$ seconds, or a difference of only $\cdot 09$ second, showing that the orifice of the jet was sufficiently well formed.

With reference to the statement, that the pressure produced by an issuing jet of water striking on a surface was double that which was due to the head from which the water came, that was only true in a sense; and the conclusions based upon it appeared to be erroneous. In Tredgold's Tracts,[1] previously referred to, it no doubt was stated. A jet coming out of an orifice would produce double the pressure due to the height it came from; but it must operate upon a disc sixteen times the area of the jet itself. But if the disc was only of the size of the jet, the jet produced no more pressure on the disc than was due to the head from which it came. It was clear, therefore, that this theory of the pressure being double that due to the head, had no connection whatever with the action of the Injector; besides the best effects had been obtained from small adjutages, or receiving discs, and not from large ones.

2nd experiment.—The orifice of the jet was $\frac{1}{5}$th of an inch diameter, the adjutage being $\frac{5}{16}$ths of an inch diameter.

	Diameter of orifice of jet in inches.	Diameter of adjutage in inches.	Head opposed. Ft. In.	Percentage received by adjutage.	Percentage recoiled.	Useful effect, viz., quantity received by adjutage, multiplied by height of opposing head; as compared with quantity issuing from jet multiplied by head, to produce flow.
2.	$\frac{1}{5}$	$\frac{5}{16}$	2 0	83	17	41½ per cent.
3.	„	„	2 8	65·3	34·7	44 „
4.	„	„	2 11	64·4	35·6	47 „
5.	„	„	3 0	62	38	46½ „
6.	„	„	3 1	58	42	44·7 „
7.	„	„	3 6	44·6	55·4	39 „
8.	„	„	3 11⅜	0	100	0 „
	Then put on an adjutage of $\frac{3}{16}$ths of an inch diameter.					
	$\frac{1}{5}$	$\frac{3}{16}$	2 0	83	17	41½ „
	„	„	3 0	62	38	46½ „
	„	„	3 11¾	0	100	0 „
	Then put on an adjutage of $\frac{1}{8}$th of an inch diameter.					
	$\frac{1}{5}$	$\frac{1}{8}$	2 0	20·7	79·3	10·35 „
	„	„	3 0	14·5	85·5	10·87 „
	„	„	3 11½	0	100·0	0 „
	Then put on an adjutage of $\frac{1}{16}$th of an inch diameter.					
	$\frac{1}{5}$	$\frac{1}{16}$	2 0	11·7	88·3	5·8 „
	„	„	3 0	9	91	6·7 „
	„	„	3 11¾	0	100	0 „

From these experiments it would be seen, that with a constant jet of $\frac{1}{5}$th of an inch diameter, acting on adjutages varying from $\frac{5}{16}$ths of an inch to $\frac{1}{16}$th of an inch diameter, the amount received, and the useful effect at 2 feet and 3 feet opposing heads, were the same respectively, whether a $\frac{5}{16}$th or a $\frac{3}{16}$th adjutage was used; but that the total height to which the column could be maintained was rather greater with the $\frac{3}{16}$th than with the $\frac{5}{16}$th adjutage, being, in the case of the $\frac{3}{16}$th adjutage, up to $\frac{1}{4}$ of an inch of the head producing the flow; and in that of the $\frac{5}{16}$th adjutage, up to $\frac{2}{5}$ths of an inch of such head. With the smaller adjutages of $\frac{1}{8}$th of an inch and $\frac{1}{16}$th of an inch, it would be remarked, that while far inferior results were obtained at the lower opposing heads of 2 feet and 3 feet, no benefit was found in any addition to the ultimate height of the opposing head.

[1] 'Tracts on Hydraulics,' etc. 8vo. London. 1836. Page 208.

He thought the Members owed a great deal to the Author for the trouble he had evidently taken, to lay before the Institution the opinions of French scientific men on this subject; and when it was recollected that the Injector was a French invention, and that French Engineers were extremely scientific and ingenious, there would be no question that such a Paper must be an exceedingly interesting one. The Table put forward by the Author to illustrate the Paper appeared to be thus constructed:—In one column there was the weight of steam issuing from the jet in a given time; in another column, the supposed weight of water that could issue from the adjutage in the same time; and then was given, the amount of water the issuing steam could take up, and the pressure at which it was able to enter the vessel. The two last results he believed to be true; but the reasons for them given in the Paper, which reasons appeared to be those of French scientific men, seemed to him to be of the most curious and confused character. They amounted to this:—that the effect was due to the spheroidal state of the particles of water in the sheaf; that a number of globules were set into rotatory motion, and by some mystery in the action due to the form of the receiving tube; this rotatory motion was converted into direct motion; and that in this conversion of rotatory into rectilinear motion lay the source of the power of the Injector. Now he could not conceive that it was inevitable any rotatory motion should be set up at all, nor if it were, how its conversion into rectilinear motion would produce any other effect than a loss of power. It was impossible to believe, that this was the proper theory of the action of the Injector. In the course of the discussion, the action of the Injector had been compared, Mr. Bramwell thought very aptly, to that of a bullet from a gun. According to the French savants, the bullet, to have any action must be fired from a rifle, and have a rotatory motion. In another explanation which was offered, the Injector was considered in the way in which it was ordinarily used, as consisting of a current of steam issuing from a boiler, and delivering a jet of water into the same boiler, and into the water of that boiler. Now, although it had not been so stated, the fact of course was that the jet of water might go back into the steam, were it required to do so; but that explanation of the action of the Injector last referred to involved, or appeared to involve, the necessity that the jet should be delivered into the water in the boiler, and did not account for the fact, that it might be delivered into the steam.

In endeavouring to explain his views of the action of the Injector, he would illustrate them by comparison with well-known implements. Assuming a case in which there was steam, 400 times as light as water, that that steam was acting on a piston in a cylinder of any

area, and that on the other side of the piston there was a piston-rod, $\frac{1}{400}$th part of the area of the cylinder; then such rod would represent the bulk the steam would assume if its 400 parts, by volume, were condensed to the density of water. That steam so condensed would then occupy the size of the piston-rod.

Now it was obvious, that if the steam were suffered to press on the piston while a piston-rod of $\frac{1}{400}$th of the area were driven against any substance, solid or fluid, that rod being only $\frac{1}{400}$th part the area of the piston, would exert on each unit of the surface opposed to it an enormous pressure, and might be compared, in its penetrative effect, to the action of the small area of a needle on which a large pressure was brought to bear. This would be the effect, if the piston-rod were the $\frac{1}{400}$th of the area of the piston; but if this piston-rod were 20 times as large, so as to be $\frac{1}{20}$th of the area of the piston, and its force on each unit of surface opposed to it was proportionately reduced, the pressure would still be 20 times as great, per unit of surface, as that of the steam which pressed on the piston. Supposing now, that the piston and rod were withdrawn from the cylinder, and that the cylinder were made somewhat like a bottle, having a cylindrical body and a diminished neck, such neck being, say $\frac{1}{400}$th of the area of the body of the bottle, and if, as the steam were suffered to rush along the body of the bottle, it could be condensed by external application of cold, at the part where the bottle rounded away into the neck, the steam so condensed would be reduced to the size of the neck, and would represent the piston-rod mentioned in the previous illustration, and this fluid in the neck would go forward with as much force as the piston-rod in the illustration just given. From this it would follow, that if there were steam of 400 times the lightness of water, and it issued with a velocity of 1 from an orifice having an area of 400, there would then be an effect represented by 400 parts issuing with a velocity of 1, and assuming that to be suddenly condensed, it would occupy only 1 part instead of 400 parts; but the weight of the one part would still be 400, and its velocity would still be 1, so that that which came out of an orifice representing an area of 400 could go into another orifice representing an area of 1. In this manner, therefore, the condensed steam would be capable of balancing the pressure (in a vessel) 400 times as great as the pressure in the boiler from which the steam issued that had been condensed to produce this jet of water, and it would no doubt be capable of all entering into a vessel containing a pressure which, although less than the 400 times, would still be greatly in excess of the pressure that produced the flow of steam. The experiment referred to by Mr. Phipps proved that the water would all be capable of entering into a vessel having a pressure equal to $\frac{1}{7}$ of that which would balance

the head, or, in the supposed instance, about 57 times greater than that existing in the boiler from which the steam flowed. This would be the case if the steam were condensed, by the application of external cold; but if this were done, no useful purpose of taking in extra water, as feed-water, would be served. But if the condensation of the steam were effected by the admixture of other water, then the area of the neck of the bottle must be enlarged, because the effect would be to increase the area of the jet, by the direct addition of the water, and also by the speed of the jet being diminished by the increase of the weight. From this cause of diminished velocity, the effect of the jet on each unit of area would be proportionately decreased, and it would no longer be capable of entering into a vessel against a pressure so great as 57 times that from which it issued; but it would be manifest, that the amount of water that might be added to the steam would be very large, before it would be no longer capable of causing the whole combined volume to enter the vessel having in it a pressure only equal to that of the steam. He trusted this simple way of looking at the Injector, viz., that it was an implement by which the energy of a fluid issuing from a large orifice could be concentrated and made to act on a small orifice, was one which would be received as lying at the root of the theory of the action of the Injector.

It has been said that, in order to enable the Injector to act, one-third of the area of the so-called sheaf should be uncondensed steam. In the French books he had examined, he did not find the condition stated as a necessity, but as a fact. He thought, however, that there were no reliable data for this view, but that it had been assumed, in order to make the actual results harmonize with the theories of action put forward by the French Engineers. Those best competent to give an opinion on the subject in this country were not aware of any such necessity, but on the contrary, thought such a condition of things would be detrimental.

When this instrument was first brought, by Mr. Robinson, before the Institution of Mechanical Engineers, in the year 1860, Mr. Bramwell had given an illustration of the cause of action of the Injector, which he now asked permission to repeat:—Suppose that, in a tank containing 10 feet or 12 feet depth of water, there were fitted, near the bottom, a valve opening inwards. It was perfectly understandable, that if the jet of a powerful fire-engine were directed against this valve, a pressure might be exerted against the valve such as to force it open, so that the jet would enter the tank. Next, if in lieu of the jet being produced by a fire-engine, it could be caused by means of the momentum of steam issuing from a boiler, then what must be the pressure of the steam in that boiler, in relation to the head of water in the tank. It was easy enough

to believe, that the momentum of the steam issuing from a boiler, with some degree of pressure, would be sufficient. Therefore, given a tank with a resistance of a certain head of water, and given a boiler with a proper pressure of steam, a jet might be produced sufficient to overcome the resistance. The point then remained, how low might the steam pressure be. It turned out, from experiment, that it might be equal to, or even less than, the head of water in the tank; and this being once ascertained, the mode of action of the Injector was no longer a mystery.

On the same occasion he had ventured to give the following illustration, to show that the whole of the steam should be condensed, in order to get efficient action:—Again, assuming the tank with its 10 feet to 12 feet depth of water, and its valve opening inwards, as before, then suppose that against this valve a solid steel bolt of 1 lb. weight were thrown, with such a velocity that it would force open the valve and enter. This might be compared to the state of things when the whole of the steam in the jet was condensed, so as to have produced that which he had before called "solid water." Now, if this 1 lb. weight of steel, instead of being in the form of a solid bolt, were made into a spiral spring of equal diameter to that of the bolt, and such spring were thrown with a velocity equal to that of the bolt against the valve, it might well be that the spring would not be capable of opening the valve, because a large part of its momentum would be expended in collapsing the coils of the spring. This state of things might be compared to that of the jet, when it was rendered elastic by containing uncondensed portions of steam. Entertaining these views, as to the advisability of the whole of the steam being condensed, he was surprised to find it put forward in the Paper, that it was a necessity that one-third of the jet should be composed of uncondensed steam;—a view which, he must repeat, he believed to be entirely erroneous.

With regard to the limits of pressure to which the Injector could be worked, Mr. Bramwell was inclined to think that, when the steam had become so dense that it could not carry along with it enough weight of water to condense it, the instrument could work no further to deliver the whole of the water; but that point required steam so high that the application of the Injector was quite suitable for locomotives working with 150 lbs. to the inch. Such a pressure as this was as high as would probably be reached for some years to come, and therefore the question of the limit of pressure to which the Injector was applicable was one rather of scientific than of practical interest.

He was surprised at the statement made by the Author, when comparing the Injector with feed-pumps, that the latter consumed

2·3 cubic feet of steam for every cubic foot of water supplied. He could not tell how this conclusion had been arrived at, unless indeed the ratio of the cylinder and of the pump of a donkey-engine were taken; but even then it appeared to have been forgotten, that, when an engine, say a locomotive, was at work, the feed-pump was working off the main engine, and not off the donkey. It was clear that, irrespective of friction, one inch of steam was capable of feeding into its boiler one inch of water. This was without expansion; but the main engines of a locomotive worked with a considerable degree of expansion; and therefore the calculations must, he thought, on this point, be very wide of the truth.

There was one interesting subject which had been hardly touched upon, viz., the applicability of the Injector to marine engines. As far as he had heard, their use in steamboats had been limited, and the result of such use had been of a rather unfavourable character. It would be of great benefit, if the cause of these results could be investigated, and be properly understood; so that if possible the difficulties might be remedied, and the Injector be rendered capable of use in marine steam boilers, which he believed were now the only class of boilers to which the Injector was alleged to be inapplicable. As to its efficiency in the locomotive, it had been stated that none of the new engines of the London and North Western Railway Company were furnished with pumps, but reliance was placed solely upon the Injector. Speaking from recollection, out of the whole number of locomotive engines exhibited, in 1862, by British and foreign manufacturers, only about two-thirds had Injectors with feed-pumps, while one-third had the Injector alone, and only one locomotive was without an Injector.

The great advantage attending the application of the Injector to locomotives, was evident to every engineer who merely travelled by a train drawn by an engine to which the Injector was fitted. Such traveller would then notice that, in the case of a stopping train, the instant the steam was shut off, the Injector was put to work, and the feed driven into the boiler, all the time the engine was standing at the station. Whilst the instant the engine was started again, the Injector was stopped; and thus the engine-driver, being provided with an implement capable of feeding the boiler, irrespective of the engine being in action, was enabled to avail himself of all stoppages, as well as of all easy running ground, to get feed-water into the boiler, and so to permit the engine to act with full vigour, and undiminished by having to heat the incoming feed-water at those times when the heaviest demands were made on its exertions.

Mr. SIEMENS said, the areas of the different jets of water

and steam, which had been stated to be adopted in practice, agreed very well with his own calculations.[1] The areas were determined by the quantity of steam necessary to condense in order to impel the water. Taking the case of a pressure of 60 lbs., or an effective pressure of three atmospheres, the steam was 477 times lighter than water, while its velocity was only in the ratio of $\sqrt{477}$, or nearly 22 times greater than that of the water; the consequence was, that the area must be larger to allow a given weight of steam to issue from an orifice, than if water issued under the same pressure, in the proportion of $\sqrt{477} : \sqrt{1}$, or about 21 times the area. But, inasmuch as the quantity of water had to be increased ten-fold, it followed that $\frac{1}{10}$th of 21 times, or 2·1 times, ought to be the area of the steam orifice as compared with the orifice in the boiler. This calculation agreed accurately with the proportions it had been found expedient to adopt; but he was surprised to learn that the same proportions of area were given to the Injector, although the conditions of its application, especially as regarded the pressure in the boiler, might be very different. With a pressure of twenty atmospheres, for instance, the density of the steam was 110 times that of the water; therefore, the relative velocity would be as $\sqrt{110} : \sqrt{1}$, or as 10·5 : 1, and about double the area of steam would be required to supply the necessary quantity to impel the water forward into the boiler. He felt convinced many of the partial failures they had heard of might be due to this,—that the Injector had been calculated, or determined experimentally, for ordinary high-pressure engines, but if applied to low-pressure, or very high-pressure engines, it failed to work satisfactorily. It could even be shown, that the Injector was not applicable at all if the pressure exceeded certain limits. As, with a pressure of twenty atmospheres, the velocity of the steam was only 10·5 times greater than that of the water, and as the steam must take up about 10 times its own weight of water in order to condense, it would consequently possess only just power sufficient to impart to that amount of water the requisite velocity, when that point would be reached, where the Injector would no longer work with water of ordinary temperature.

The Author had referred to the dynamical theory of heat, and had said, that a sudden change in the sheaf took place, when there was an instantaneous conversion of heat into work, a vortex being found in the sheaf, producing this result. Mr. Siemens had been one of the earliest disciples of this new theory of heat; and in the year 1853,[2] a Paper by him was read at the Institution in which

[1] *Vide* Institution of Mechanical Engineers, Proceedings. 1860. Pages 48-78.
[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xii., p. 571.

the caloric engines were passed in review by the light of that theory. Taking the case of a pressure of 60 lbs., the force represented by a jet of steam issuing out into the atmosphere was simply the product of the column in feet representing that pressure, multiplied by the weight of steam in lbs. issuing in a given time. The column representing the pressure of steam of four atmospheres total pressure was, according to the table, 45,792 feet; —that was, steam of a pressure of 60 lbs. would be produced by a column of its own weight 45,792 feet high. Therefore, 45,792 foot-lbs. was the mechanical work due to 1 lb. of that column of steam. Now the quantity of heat contained in 1 lb. of steam was 1,150 units. These 1,150 units of heat produced in the Injector 45,792 foot-lbs. of work, or for every unit of heat $\frac{45,792}{1,150} = 39{\cdot}8$ foot-lbs. The full mechanical equivalent of a unit of heat was however = 772 foot-lbs., or units of force, and therefore the maximum useful effect of the Injector did not exceed $\frac{39{\cdot}8}{772}$, or about the twentieth part of the theoretical effect due to the heat in the steam. A good expansive steam-engine would give as much as one-sixth part of the full theoretical effect due to the heat expended, and supposing that there was 33 per cent. loss in an ordinary pump, it followed that water could be raised with an expenditure of $6 + \frac{33}{100} = 8$ times the theoretical expenditure of heat, instead of 20 times that quantity which the Injector required. Consequently, the Injector could only be advantageously applied, when the water was required to be both heated and raised; and it could never compete with an engine and pump for simply raising and propelling water.

Mr. J. C. Craven remarked, that the Injector would not feed water into a boiler in which the pressure exceeded 150 lbs., whereas no similar difficulty was experienced with pumps. He was of opinion, that better results were obtained when working with pumps, in consequence of its being possible to heat the water in the tender when standing, or with spare steam when running.

Mr. Hawkshaw, Past President, said, the Lancashire and Yorkshire Railway Company were amongst the first to apply the Injector to their locomotives, and it had been found to be a very simple matter to supply water, by its aid, to a boiler having a pressure within it of 150 lbs. He thought the Injector, as he believed every one would be disposed to admit, was a complicated machine, and difficult to explain; but some objections which had been raised to it might be easily answered. In the first place it had been stated, that the Injector when applied to an engine of 30 lbs. pressure did not act at

all, and it was efficient when attached to a boiler of 70 lbs. pressure. No doubt that would be the case; a certain pressure of steam was necessary for its action or advantageous use, while with a lower pressure it might not act at all. It was, to a certain extent, a case of 'vis viva' against 'vis inertia,' and without going into any elaborate calculations, but dealing with it as a purely mechanical question, it was plain the pressure of the steam might be brought so low, that the Injector would be of no value. It had not been proposed, that the Injector should be universally applied, and that it should supersede pumps in all cases. With regard to the hydraulic apparatus put forward to illustrate its action, he apprehended it had no relation to the subject, and that it could not be compared, or contrasted, in any way, with a delicate instrument like the Injector. An inspection of the drawing (Fig. 1, page 230) illustrating those experiments, indicated at once how a worse result was obtained, in proportion as the column of water was raised. The water acted by force of impact, and in the issuing column of water, the particles of water were dispersed to such an extent, that instead of getting greater force of impact, that force was diminished. Thus, if the water was dispersed into mist, only a certain proportion of that mist was thrown upon the opposite orifice which had a fixed size. In this way the higher the column was raised, the less force of impact was secured. These experiments had, in his opinion, no relation to the question, and neither proved nor disproved the principle on which the Injector acted. In the experiments recorded by Tredgold, to which allusion had been made, twice the pressure due to the head only was produced with a disc sixteen times the size of the orifice. If the particles of water were dispersed, the area of the disc must be increased. It was clear the action of this instrument depended upon the simple fact, that a force, or pressure, was created at the orifice leading from the tuyère greater than the resistance of the water within the divergent tube that led to the back-pressure valve. Whether that force could be partially explained by an experiment which could be easily tried, he did not know; but supposing, from a Perkins' gun, bullets of a given diameter were projected upon a valve of the same diameter, the same action, to some extent, would be obtained, and the force of that action might be increased in the manner explained by Mr. Siemens. None of the objections raised to this instrument militated against its operation, so far as he could judge; and his impression was, that so long as care was taken to insure that its proportions had a proper relation to the pressure of the steam to be dealt with, it might be made applicable to nearly all high-pressure boilers, and he thought the present difficulty of its use with low-pressure boilers was one which might be overcome.

Sir WILLIAM ARMSTRONG said, it was known that when steam issued from an aperture it acquired a velocity vastly greater than a jet of water issuing under the same pressure. If after the aqueous matter had acquired that high velocity as steam, it was converted into pellets of water, those pellets would retain the velocity of steam while they would occupy an incomparably smaller compass, and therefore would be able to enter against the pressure of the boiler. In fact, a large jet of steam was converted into a small jet of water without diminution of velocity. Had it remained in the form of steam, it would have been too voluminous to enter, but as water it was sufficiently diminished in sectional area to force its way in. Not only would it have power to do this, but it would have a surplus velocity capable of carrying additional particles of water along with it into the boiler; but if asked how much additional water would thus be carried into the boiler he could not answer. There were so many questions of friction and slip, that nothing short of actual experiment could determine the fact. He did not think this was a hydraulic question, or that the results could be imitated by hydraulic pressure where there was no condensation of steam. He did not believe any jet of water issuing under pressure of a given head would produce effects analogous to those obtained in this instrument. There must be the high velocity of the steam, and the diminution of volume due to condensation, to obtain the necessary penetrating effect. Not only did he consider that it was incapable of being illustrated by hydraulic apparatus, but also by anything on the principle of the air-gun. At the meeting of the British Association at Newcastle, an instrument was produced, to illustrate the action of the Injector, in which bullets were put into motion, and that through a tube, when they acquired sufficient velocity to enter a chamber in which the pressure was equal to that by which the bullets were propelled. He thought that was a different question. The bullet acquired its velocity by a continued pressure operating through a long tube, and of course would acquire sufficient momentum to overcome an equivalent resistance operating not in a prolonged tube, but only at the point of entrance. A concentrated pressure would thus act at the entering orifice, which was a different action altogether. With regard to the proportion of steam to the quantity of water injected, it would be more satisfactory to know what the instrument actually did by experiment, than what it ought to do by calculation. He would say generally, it appeared to be one of the most refined, elegant, and ingenious instruments ever brought before the public, and he felt bound to express his admiration of it.

Dr. JOULE observed, through the Secretary, that having seen a

model of the Injector, and also the apparatus at work, he thought the theory might be thus explained:—At the point where the steam was commingled with the water supply, the motion was so rapid, that it appeared to be carried along to a considerable distance before it was completely condensed. Therefore, the velocity at all points between this and the lower pipe by which it entered the boiler might be nearly the same, because the steam was gradually condensed during its progress down the tapering tube. This was a state of things which would make the penetrating power of the water at the lower pipe greater, for the unit of area, than it was where the steam and water first met, in the inverse ratio of the areas at the respective places. In fact, the jet might be considered as composed of tapering steam filaments, and nearly uniform water ones; when the wide end would be thrust by the steam as if it were the base of a solid cone, and the total pressure on the wide end would be equal to the total pressure at the narrow end. Hence the pressure for unit of area in the narrow part would be greater than that in the wide part; and the latter being the pressure of the boiler, the former would be able to overcome it.

Mr. George Bidder said, if this were simply a question of practical engineering and experience, he should not venture to offer an opinion upon it; but as the explanation of the action of the Injector involved theoretical considerations, he might perhaps be permitted to say a few words—on the theory only. The explanations that had been given as to the action of this instrument had, so far, failed to convince him, and he had spent some time in endeavouring to arrive at a more satisfactory result.

The Author referred to the motion of the water in spherical particles, but he could not see how the form of the water, as it went through the sheaf and impinged on the valve, affected the question. It was, in his opinion, entirely a matter of momentum and velocity; and whether the water were in a condensed form, or in a semi-condensed form, the momentum must be the same, and the motion the same, whatever the form of the water. How then was the fact to be accounted for, that steam issuing out of a boiler, having a certain pressure within it, could overcome that identical pressure at the valve in the lower part of the same boiler? Dr. Joule's illustration seemed to be an evasion of the well-known hydraulic principle, that the pressure of the water was the same in every direction; and it appeared to suppose, that by narrowing the outlet the pressure could be increased, as by lengthening the arm of a lever its power was multiplied. Another view was based on the supposition, that under certain circumstances a current of water would balance more than the corresponding head of statical pressure. That theory appeared to be opposed to all hydraulic

principles, and to the mathematical formula of pressures of running streams, as expressed in the well-known formula

$$p = g\,r\,h - \tfrac{1}{2}\,r\,v^2,$$

where p was the pressure, r the density, v the velocity, and h the head.

That seemed conclusively to show, that in a running stream less than the statical column would be obtained, unless the inlet velocity were entirely destroyed, when the pressure would be equal to the statical column. That principle accorded with Mr. Bramwell's experiments. He had a running stream with a tube and a vertical column to balance it, and he got a height of something less than the head of the stream; therefore the pressure it would balance was something less than the height which represented the velocity of the running stream. There were other portions of these experiments which were not so satisfactory as to the cause of the phenomena; nevertheless he thought that, under certain circumstances, if enough of the issuing stream was wasted, a balance might be got more than the height of the statical pressure. But it had been stated, in reference to the Injector, that when it was in proper work there was no waste; that the whole of the stream impinging on the valve of the boiler went into the boiler; and therefore that seemed to dispose of that explanation. He had also imagined that the steam, being suddenly condensed, raised the temperature of the water, and developed by the expansion high pressure. But, on further reflection, this was deemed to be an incomplete solution; and he should have been at a loss, but for a suggestion his father made, which at once, in his belief, afforded the key to the true cause of the phenomena. The difficulty was, how the pressure acting on the inlet valve to the boiler was overcome, when there was only the same pressure of steam passing out by the Injector. He apprehended the fact was, that the steam got a velocity due to the head, representing the pressure in the boiler, according to the ordinary hydraulic formula; but it was a head of steam, and not of water, and the velocity was that due to a column of the height of steam which represented that pressure. Take, for instance, a pressure of 1 lb. of steam; as steam was 1,600 times as light as water, there would be a column 1,600 times as high as the water column to represent the velocity of the steam; therefore the steam issued at 40 times the water velocity of the same pressure; and when condensed into water that water would impinge on the valve with 40 times the necessary velocity required to overcome the pressure on the valve. If mixed with twenty or thirty times its weight of cold water, it would still have a greater velocity than was necessary to overcome the pressure from the boiler, and that showed that for low pressures of steam it would carry with it a

much larger quantity of water than it would for high pressures. For a pressure of 1 lb., the steam would be 1,600 times as light as water, and there would be a velocity of 40 times the water velocity. For a pressure of 14 lbs., the steam would be 850 times as light; and the velocity would be 29 times that of the water. At a pressure of 84 lbs., it would be 212 times as light, and the velocity would be 14½ times that of the water. While at a pressure of 224 lbs., the steam column was 100 times as light as the water column, and the velocity would be 10 times that of the water. According to that view at low pressures, the steam carried about thirty times its weight of water into the boiler, and at high pressures only eight or nine times its weight of water. He thought that explanation showed the reason why the water would not go in at above a certain temperature. If the temperature was too high, it had not time to condense the steam, and unless the steam were condensed, it had not sufficient density to enter the boiler. With reference to the Injector, as a motor, it would appear, looking at these figures, about as extravagant a method of employing power as could possibly be adopted.

Mr. ZERAH COLBURN remarked, that the delivery of the Injector was greater as the pressure increased. It was not merely the velocity of the current of steam that produced the effect, but also its weight. A pound of steam in motion was merely a pound of water moving at that velocity. He had not heard the point raised in connection with the Injector as to the amount of work actually done, or the power consumed, in getting the water into the boiler. It seemed to be the idea of some persons, that the Injector was an approach to perpetual motion, with no loss of power, except loss of heat from radiation and friction. But a simple experiment might be made which would show what the loss was; as it would only require that the water should be drawn from one measuring tank, and be forced under a loaded valve into another. If 100 gallons were taken out of one tank, and 110 gallons were found in the other, then 10 lbs. of water, as steam, would evidently have been used. Then, from the original and final temperatures of the water, and the weight of steam used, it would be easy to see whether the same temperature was attained as would be had by simply mixing the steam and water. In the Paper the history of the Injector was spoken of, and the experiments of the Marquis of Worcester and of Savery were referred to. But in these, the effect was that, simply, of the pressure of the steam employed, and it was only in Manoury d'Ectot's experiments that the induced current was employed. The history of the Injector, though perhaps not of great importance, was nevertheless interesting. In Hero's book, 200 B.C., an account was given of a jet of steam employed to blow upon fire. The steam alone would

have put out the fire, and the jet could have only acted usefully, by drawing in and forcing air upon the fire. The first patent for a steam jet, to draw and force air along with it, was that of J. Barber, for the purpose of blowing air into blast furnaces, by whom it was patented A.D. 1773; and again in 1792, on which latter occasion a clear description was given of the 'rationale' of the jet. There was no doubt, from Davies Gilbert's letters to Nicholson in 1805, that Trevithick used the induced current, and that the effect it produced was distinctly understood. The year after that Nicholson took out a patent, in which the action of the jet was described, and as applied to the drawing in and forcing currents of water. He begged to hand in these specifications, for the benefit of those who were interested in the subject. He particularly directed attention to the first scheme of Barber's, which was a very remarkable one, while that of Nicholson was especially interesting.

Mr. GEORGE BIDDER explained, that he did not say the absolute feed would be less, but that the weight of cold water in comparison with the weight of steam would be less, in proportion, for high pressures than for low pressures.

Mr. HAWKSLEY, V.P., said, in common with many others his attention had been attracted to this instrument, and in the main he agreed with the solution of the problem which had been presented by Mr. George Bidder. But the question as to the work the Injector would perform had not been sufficiently touched upon, although this might be determined in the simplest manner, excepting as regarded loss from friction, and from the occasionally imperfect form of the instrument, even when it answered the particular purpose intended. The weight of water which the Injector was theoretically capable of carrying into a boiler might be represented by the product of the weight of the steam used into the square root of the expansion of a unit of water into steam multiplied by the co-efficient of impulse; that would represent, say (n) = the number of times the weight of the water in the steam which the Injector was capable of placing in the boiler. Suppose, for instance, the absolute pressure of the steam was that of two atmospheres, or one atmosphere above the ordinary atmospheric pressure, then the expansion of the steam was about 900 times the bulk of the water from which it was generated. The square root of that was 30, and this would be a theoretical multiple of the water in the steam which the Injector was capable of carrying into the boiler. Again, at ten atmospheres, or 150 lbs. pressure, the steam would assume an expansion of 203 units; then the weight of water which would be carried into the boiler, including the weight of the steam, would be about 14 times the weight of the steam; practically it was found to be about 10 times; the

difference was caused by the fact that the steam, in coming through the passages, encountered a vast amount of friction.

The very simple expression referred to was thus derived :—

Let a = the absolute pressure (in atmospheres) within the boiler.

Then $(a - 1)$ = the active pressure in excess of the atmospheric resistance.

Let $(2\,g = 64)$ = the ordinary co-efficient of gravity for velocities in feet per second.

Let 34 = the height in feet of a column of water equal to the pressure of one atmosphere;

and let ϵ = the multiple of the unit of water necessary to represent the volume of steam into which the unit was expanded at the given pressure at which the Injector was to operate.

Then $\left(\frac{\text{velocity of steam}}{\text{velocity of water}}\right) = \frac{\sqrt{2g \times 34 \times (a-1) \times \epsilon}}{\sqrt{2g \times 34 \times (a-1)}} = \sqrt{\epsilon} = n$

= the number of times the weight of the steam which would be carried as water into the boiler by the impulse of the steam when again condensed into water.

This expression represented the velocities due to the heights of the respective columns of steam and of water which opposed each other. The denominator divided the numerator, leaving only the simple form $\sqrt{\epsilon} = n$, applicable to all practical pressures exceeding the pressure of one atmosphere—providing the influx water be cold enough to condense the whole of the effluent steam.

From this expression the complete effect of the apparatus might be estimated thus :—

Let d = smallest diameter of steam nozzle in inches,

q = cubic feet of water to be added to the boiler in an hour.

Then,

$$q = 3600 \times \frac{\cdot 7854 d^2}{144} \times \frac{\sqrt{2g \times 34 \times (a-1) \times \epsilon}}{\epsilon} \times \left(\frac{\sqrt{\epsilon} - 1}{\sqrt{\epsilon}}\right) \times n.$$

Omitting the last factor but one as (commonly) unimportant, and substituting $\frac{p}{15}$ for $(a - 1)$, there was finally obtained

$$q = 237\, d^2 \sqrt{p},$$

in which p = pressure in lbs. above the atmosphere.

It was probable the losses by friction, &c., might in extreme cases amount to one-third ; therefore practically it might be assumed that

$$q = 160\, d^2 \sqrt{p};$$

and as the instrument should be adapted to do its work by operating during half time, it should be constructed on the formula

$$q = 80\, d^2 \sqrt{p}; \quad \ldots\ldots \text{A}$$

whence $$d = \sqrt{\frac{q}{80\sqrt{p}}}. \quad \ldots\ldots \text{B}$$

By the aid of the formula (A), Mr. Hawksley had constructed the following

TABLE of Cubic Feet per Hour, to be placed in the Boiler, or (equivalently) the Nominal HP. of the Injector (Mr. Watts' Standard of 1 c. f. per HP. per hour).

Diameter of Jet in Inches.	Steam Pressure in lbs. above the Atmosphere.										
	4	9	16	25	36	49	64	81	100	121	144
0·5	40	60	80	100	120	140	160	180	200	220	240
0·6	57	86	115	144	173	202	230	269	288	317	346
0·7	78	118	157	196	235	274	313	353	392	431	470
0·8	102	154	205	256	307	358	410	461	512	563	614
0·9	130	194	259	324	389	454	518	583	648	703	768
1·0	160	240	320	400	480	560	640	720	800	880	960
1·1	193	290	387	484	581	678	774	871	968	1,065	1,162
1·2	230	346	461	576	691	806	921	1,036	1,152	1,267	1,382
1·3	270	405	541	672	811	946	1,082	1,217	1,352	1,487	1,622
1·4	314	470	627	784	941	1,098	1,254	1,411	1,568	1,725	1,882
1·5	360	540	720	900	1,080	1,260	1,440	1,620	1,800	1,980	2,160

He believed that simple formula might be regarded, making allowance for friction, as the true representation of the effects of the Injector, when working continuously under favourable conditions, in regard to the temperature of the feed-water. There were many circumstances to be pointed out, in regard to the form of the Injector, which was in some respects philosophically defective. For instance, the water tube ought to be parallel instead of being expanded, because by being made broader at the lower end it gave an increased effect to the opposing force of the water. Moreover, it ought to be sharp-edged at the bottom—as sharp as possible—for when the tube was made parallel and sharp-edged the height to which the opposing column of water would rise was only two-thirds of the height to which it would attain when passed through a conical nozzle. There were many curious questions connected with this subject, but all perfectly intelligible, and capable of being reduced to calculation. He entirely disagreed in the opinion which had been expressed that this was not a hydraulic question, for he believed the problems connected with this interesting instrument could be solved by none other than the methods which were employed for the solution of problems of a purely hydraulic nature. One condition he would mention; that was,

that the steam, in order to produce the proper effect, must be converted into water before it came into contact with the feed-water. If it was not condensed, the apparatus would either cease to act, or act imperfectly, as was known to be the case. Though nothing was positively known respecting the constitution of water when in the shape of steam, whether it existed as vesicular vapour, or whether the caloric surrounded and separated little particles of solid water—yet unless the caloric quitted the particles of water, they could not act effectively against other particles, like shot against shot. The inflowing or feed-water must therefore be sufficiently cold to condense the steam before receiving the blow to enable the apparatus to act with vigour. The temperature (t) Fahrenheit of the feed-water at which the machine would commence to operate imperfectly, in consequence of not condensing the whole of the steam, would be approximately represented by the expression

$$t = 212 - 9\sqrt{p}.$$

Hence, at high pressures, the action would cease much earlier than at low pressures. Thus, in a locomotive working at 144 lbs. pressure, the temperature of the feed-water to produce the full effect should not exceed $212 - 9\sqrt{144} = 212 - 108 = 104°$; whilst in the case of a low-pressure engine, working at 16 lbs. pressure, the temperature might rise to $212 - 9\sqrt{16} = 176°$.

Mr. Hawksley added, in reply to a question, that for all pressures between 1 atmosphere and 10 atmospheres, instead of having recourse to a table of expressions, the mean constant number 1900 might be divided by the number of absolute atmospheres of steam, and the square root of this would give nearly the same result for the value of (n), as would be obtained by referring to a table of expansions, which might not always be at hand when wanted. Thus, in the case of a pressure of 10 absolute atmospheres

$$\sqrt{\frac{1900}{a}} = \sqrt{\frac{1900}{10}} = \sqrt{190} = 13\tfrac{3}{4} = n;$$

and deducting in this instance 25 per cent. for friction, $n = 10\frac{1}{4}$, which corresponded very closely with the observed effect.

The instrument was, no doubt, a bad mechanical agent, but it was extremely convenient, and was good in other respects, because the heat which passed from the boiler into the jet was carried back again into the boiler; consequently there was no positive loss of caloric; but a somewhat larger boiler was required, because steam had to be supplied not only to the engine but to the instrument also; or, in other words, to generate the steam more rapidly than would be required for the supply of the engine only.

Mr. J. Scott Russell, V.P., thought he should be able, with

the assistance of some facts, kindly supplied by Messrs. Sharp, Stewart, and Co., to give a comprehensible account of the principle and mode of action of the Injector, without having recourse to mathematical formulæ.

First, Mr. Phipps appeared to conceive that it might be all a pure contest of water columns, and that it was at the critical point, where pressure and rest were converted into motion and speed, that the seeming paradox occurred, and herein he found his solution. For two hundred years mechanical philosophers had vainly endeavoured to discover how 'vis viva' and pressure could be reciprocated into each other. The difficulty of the conciliation was this:—A fall of 1 foot produced a speed of 8 feet per second; a fall of 4 feet only produced a speed of 16 feet per second. Now every one knew, that in carrying up a weight a height of 1, and the same weight up a height of 4, the work done in travelling up a ladder four times as high as another was four times as great. Here it followed, that four times the speed travelled uniformly up a ladder gave four times the expenditure of power, and twice the speed, of a body travelling alone, and these two seemed to be equal. The difficulty did not culminate until one of the speeds was parted between two bits of matter. Now take the double speed, and part it between two bits of matter. Let the body moving with double speed come into collision with one equal to it at rest, and the joint speed became half: that was the half speed which was produced by a fall of 1 foot, instead of the whole speed produced by a fall of 4 feet. In short, a power of four split into two was resolved into a power of twice one. It was quite plain this relation between velocity and height due to speed, taken as algebraic formulæ, without regard to what they were doing, got them into a paradox. To reconcile the seeming contradictions of this case, he took an example. The question was, whether a vessel filled with water and steam, having a steam pipe led out of the steam part of that vessel, and into the bottom, could be made to inject water into itself. Taking the case of a pressure of steam of 50 lbs., with a No. 8 Injector, so called because the diameter of the entrance was 8 millimetres, the steam nozzle, or aperture, would thus be ·001056 of a square foot; and let the temperature of the feed-water be 85°, and of the delivery-water 160°, to ascertain first, what was the pressure which prevented the entrance of the water; and secondly, what was the speed with which the water would rush out to prevent the feed-water rushing in. The head of water due to that pressure of steam would be somewhere about 115 feet, and the speed due to that head was 85·6 feet per second. That was the speed with which the water tended to rush out, and the difficulty was, how to make it rush in faster the other way. He at one time thought, as others

probably had done, that a vacuum was created, which kept the water out of the way, and that a jet of water was sent into the vacuum before the water could recoil in time to stop it. He fancied that something of this kind occurred in a tender, when a jet of steam rushed into it; but he learnt there was, in reality, no such phenomenon in this case, the water passing quietly and evenly through the Injector. But what did happen was owing, he believed, to the wonderful rapidity of condensation. By carefully watching a marine engine, and looking at the mercurial gauges on the body of the condenser, and the pipes leading to the condenser, it would be observed how instantaneous was the annihilation of the whole of the steam in the cylinder, so that before the port was well opened, the cylinder was emptied of its steam, and the condenser was no fuller. It was inconceivable with what rapidity condensation took place. Let that fact be borne in mind in the further consideration of this question. What had next to be determined was, the rapidity with which steam would rush from a boiler, where it was contained by high pressure —say of 50 lbs., into a condenser, where it was to be condensed. That speed might be easily calculated, because the height due to the atmosphere of steam, and the velocity due to that height, gave the speed, at which the steam would rush to be condensed, as 1,796 feet per second. That was the issuing speed due to pressure. In going through this process, water and steam must be considered as the same thing, although at the same time different in themselves. First, the steam in the boiler rushed out, under a certain pressure, to be condensed. Then on its way it must be imagined to be gradually getting chilled. This chilling made no change upon the velocity of the water, but it brought about a great change in the bulk which the water occupied. Now suppose this tapering jet of cooling steam to come in contact with a hollow cone of cold water, and this cone of steam gradually shrinking down till it became only a pure rod of water, this rod of water would still rush over at the rate of 1,796 feet per second. But it was plain, that it would very soon stop, provided it had no escape; and the next question was, how did the mixed steam, water, and condensing water, issue out of this condenser with force enough to drive in the pressure of the water on the other side? The following elements were known:—there was a volume of steam going through the aperture in this apparatus amounting to 1·89 cubic foot per second, and weighing only ·07 lb. of water, which was the driving power. The quantity of water necessary to condense that amount of steam rapidly was 0·95 lb., and this was the driven water. Let the latter be divided by the former, and the result showed that there was 13·6 times as much water to be driven as the driving water, or including the steam, which had got to carry

itself in, this quantity became 14·3, as the weight of water and steam together to be driven in.

The following summary might be useful :—

Pressure	50 lbs.
Injector	8 millimetres diameter entrance.
Steam-nozzle	·001056 of a square foot.
Feed-water	85°.
Delivery-water	160°.
Velocity of water due to head of pressure 50 lbs.	Head 115 feet, speed 85·6 feet.
Velocity of steam due to pressure . . .	1,796 feet per second.
Volume of steam going through the aperture per second	1·89 cubic foot.
Weight of steam per second	0·070 lb.
Condensing water necessary is . . .	0.95 lb.

Or the weight of steam to the weight of the condensing water $\frac{\cdot 95}{\cdot 07} = 13 \cdot 6$.

Or the weight of steam + the weight of water . . $= \frac{1 \cdot 02}{\cdot 07} = 14 \cdot 3$.

Reduced speed . . . . . $= \frac{1,796}{14 \cdot 3} = 125$ feet per second.

For steam of a pressure of 100 lbs., the velocity of the water due to the head of pressure . . . . . = 121 feet per second.

He had shown that the speed produced by the water in the boiler acting to keep the feed out was 85·6 feet per second, and that the speed of the steam was 1,796 feet per second, and that all the latter had to do was to carry 14·3 times its own weight of water. Dividing the one quantity by the other, the speed of the feed was found to be 125 feet per second, and that was, generally speaking, enough to feed the boiler, and to overpower the speed, or pressure, tending to keep the feed out. A supply had now been provided, at a particular temperature and at a particular pressure, and by following out the same process in other cases, the pressures at which it would not enter would soon be ascertained. If the pressure of the steam in the boiler was raised to 100 lbs., and the pressure of steam in this jet was kept at only 50 lbs., this would happen :—A pressure of steam of 100 lbs. would give a column of water working outwards at a speed of 121 feet per second, or very little less than the speed of the feed, 125 feet per second, so that with a pressure of 100 lbs. it was plain a boiler having only a pressure of 50 lbs. would cease to feed it. By following these steps, it would be seen, first, how it was possible; and, secondly, what were the limits which rendered it possible. That which rendered it impossible was the higher temperature of the feed-water. This caused two evils: it destroyed the rapidity of condensation, and therefore diminished the speed of the steam which had to do the work ; and as it required a greater quantity of water it gave increased load. There were therefore an increased quantity of work and an increased load to do it with.

Mr. ROBINSON, in reply upon the discussion, said, with regard

to the argument, that for various pressures there ought to be various proportions of passages; that, for commercial purposes, it was found sufficient to take a maximum area of steam passage, in proportion to area of receiving nozzle, because there was the power of diminishing the area of the steam passage, by the adjustment of the steam needle, and it was found in practice that the same instrument would work from a pressure of 165 lbs. of steam down to 3 lbs., without a drop of water escaping from the overflow. With respect to the difficulty of working the Injector on a boiler having a pressure of 30 lbs., he thought in this instance the failure occurred from the defect in the supply of steam, which was taken from a part of the boiler where there was considerable priming, caused by the oscillation of the water; thus the laws of nature were set at defiance. As certainly as water flowed down a pipe so certainly would this instrument supply water if only the circumstances of the case were adapted to its use. He might state that the establishment with which he was connected had manufactured eight thousand of these instruments, and he knew of no instance of an Injector being sent back, because it did not answer the purposes expected from it by the manufacturers. With regard to the use of this instrument in marine boilers, the fact was on record that in H.M. steam tender 'Fox' the marine boilers of that ship had been supplied by the Injector for two years without a single instance of failure being reported, and that the officers of the ship had felt justified in removing one of the pump rams from the main pumps. With steam of a pressure of 60 lbs., water of 140° of temperature could be taken, though the Injector could not be started at that temperature. By starting at a lower temperature and by gradually working up to 140° the feed would go on; but higher than that, there was not sufficient capability of condensation at that pressure, and the apparatus stopped working. He might mention one thing which was very curious. Suppose the overflow pipe (Plate 11, Fig. 4), to be at a height of, say 3 feet, and to be kept full of water by the adjustment of the instrument. The air was thus excluded from the passage, and a larger quantity of water was delivered by the same Injector at the same pressure. Advantage was taken of this arrangement to feed hot water below 212°, by simple induction in this jet of condensed steam and water, carrying the further supply of hot water with it into the boiler. For this object a patent had recently been taken out, but the plan proposed only accomplished by a double Injector that which was more simply done by the arrangement adverted to.

Mr. W. George Beattie observed, through the Secretary, that a comparison was made in the Paper, between the feed-water heating apparatus and pumps, on Mr. Beattie's system, and Giffard's Injector. As this had a practical bearing on the appli-

cation of the Injector to the locomotive engine, and as feed-water heating had such an important effect on the consumption of fuel and the efficiency of the engine, he wished to offer a few remarks: First, the saving obtained by heating the feed-water from 50° to 212° had been shown to be 13·7 per cent., and if the steam used by the pumps be deducted as heat lost, the Author's estimate of 2·3 volumes of steam to 1 volume of water being taken, the net saving per cent. was found to be 12·4. This was very important, especially on southern railways, and in localities where the supply of coal was limited and its cost consequently high. Secondly, the relative volume of steam required to inject water by pumps had been estimated at 2·3 volumes, but it appeared somewhat difficult to arrive at an approximation to the true amount. The duty to be done was to balance the boiler pressure to force the water about 3 ft. high, and to overcome the passage of the clack-valves. Now, neglecting the benefit derived from the expansion of steam in the cylinders, one volume of steam would balance one volume of water, and the upper and lower clack-valves of the pump being similar, it was evident that the force required to overcome the passage of the upper boiler clack-valve would be equal to the force exerted in supplying the pump by the pressure of the atmosphere and the pressure due to the 3 or 4 ft. head of water above the pumps in the tender tank, together about 16 lbs. per square inch. If, then, the friction of the pump-ram in the gland be $\frac{1}{5}$, and taking the boiler pressure to average 120 lbs. per square inch, $120 + 16 + \frac{120}{5} = 160$ lbs. pressure per square inch on the pump-ram, or $1\frac{1}{5}$ volume of steam would be required to inject one volume of water. In the case of pumps worked from an eccentric pulley, the friction of the eccentric strap must also be added, and the loss in transmitting the power; but the simpler plan of working the pump-ram from the piston-rod crosshead was now preferred. He therefore thought that the assumption of $1\frac{1}{2}$ volume of steam to 1 volume of water would be more exact than 2·3. Thirdly, it had been assumed in the Paper, that the Injectors constantly used feed-water heated by the waste, or excess, steam to the highest temperature at which it could be taken, namely, 87°; but he submitted that such a supposition could not be entertained, and that it was not feasible, practically, by reason of the danger, when blowing back waste steam, of heating the water in the tank too much, and being unable therefore to inject it and keep the boiler supplied. Moreover this source of heat was not constant, and with a good engine-driver, was the exception. It had also been claimed as an advantage, that the Injector heated the water which passed through it to the boiler; but it was difficult to perceive what advantage there could be in taking the effective steam from the boiler, and returning it condensed in the

feed-water; at the best it would appear that the heat of the steam was not wasted beyond the small amount lost by its passage through the instrument. Fourthly, the objection, that the back pressure in the cylinder was increased by the contraction of the blast orifice, was almost self-evidently answered by the fact, that it was in consequence of part of the exhaust steam being diverted into the apparatus and condensed, and the back pressure or blast being thus reduced, that it was found necessary to contract the blast orifice. Here it might be remarked that, by the throttle valve at the end of the annular side pipes, the driver was enabled to cut off the supply of the exhaust steam to the apparatus, and to strengthen the blast if he desired to do so, and thus to obtain the advantages of an expanding blast pipe. Fifthly, with respect to the other objections—the extra first cost, and the liability to accident, the former was amply repaid, and experience had shown that the latter was not to be feared. Sixthly, another advantage of using heated feed-water was, that the generation of steam was not checked in so great a degree as by throwing in cold water, whether by pumps or Injectors. This was an important advantage when ascending steep gradients, or pulling heavy loads, circumstances now so common, and it was not necessary to pile on fuel, and consume it at a disadvantage, to keep up the steam. The advantage of the Injector was that it simplified the locomotive as a machine; the disadvantage, incidental to its use, that hot water could not be used. But while the simplicity of the locomotive as a machine was a desideratum, its efficiency and economy ought, he submitted, to be primarily considered; and if the use of pumps, with feed-water heaters, conduced to these results more than the use of the Injector, then the extra mechanism should not prevent their employment.

Mr. Beattie, thinking that the feed-water was probably raised to a higher temperature than 212°, while exposed to the heat of the exhaust steam, in the annular space of the side pipes C C (Plate 12), instructed Mr. W. G. Beattie to endeavour to ascertain, experimentally, if such were the case. For that purpose the bulb end of a thermometer was passed through a stuffing-box, into the current of water in the pipe below the clack box, where the water entered on the right-hand side of the boiler at K. In order to ascertain the heat of the exhaust steam also, in the interior side pipe C, the bulb of another thermometer was in the same manner introduced into the interior of the pipe near the elbow on the smoke-box side. The coal consumed was noted, and the temperature of the water in the tender tank was taken at frequent intervals, while the number of carriages and times of arrival and departure from the stations were carefully recorded. It was to be regretted, however, that the heat of the feed-water in the pipe at K could not be measured, in consequence of the glass bulb of the

thermometer collapsing, although it had been specially made. This occurred shortly after leaving Waterloo Station; but in view of the possibility of such an accident, a small cock had been screwed into the side of the pipe, and by directing a jet from it upon the bulb of another thermometer, the heat of the water was approximately determined.

The following was the summary of the results of an experiment made with the engine "Fire King," fitted with Feed-water Heating Apparatus, during a trial trip from London to Southampton and back:

Weight of engine	32	tons.
Weight of tender	16	,,
Diameter of cylinder	17	inches.
Length of stroke	22	,,
Diameter of coupled wheels	7	feet.
Number of carriages down journey	15	
,, ,, up ,,	14	
Weight of carriage loaded, each	$7\frac{1}{2}$	tons.
Total weight of train	$156\frac{3}{4}$	,,
Average speed, deducting stoppages, exact time being kept	40	miles per hour.
Average steam-pressure	120·4	lbs. per square inch.
Temperature of feed-water in tank (average)	137°	

The temperature of the water issuing from the small cock measured 208° to 210°, and allowance being made for the cooling of the stream, and the strong current of cold air on the thermometer, 212°, or even more, might be fairly assumed as the temperature of the current in the pipe at K.

The temperature of the exhaust steam in the interior side-pipe averaged 225°, rising several times to 230°. The coal consumed was 32·5 cwt., two-thirds being Staveley, a gaseous inland coal, and one-third Welsh coal, including the quantity used to raise steam. This gave a consumption of 22·46 lbs. per mile, and on the journey 20·4 lbs. per mile. The amount of water used, and the evaporation per lb. of fuel, could not be ascertained, as the condensed steam made a considerable addition to the water in the tank. The wind was easterly and high, the temperature of the air being 40° Faht.

The regularity of the steam-pressure, the temperature of the feed-water, the temperature of the exhaust steam, and the lowness of the fuel consumption per mile were noticeable.

Mr. England remarked through the Secretary, that in the course of this discussion it had been inferred that he attributed useful work to the form and state of rotation of the matter composing the 'sheaf.' This inference was erroneous. The actual form of the matter,—'minute spheres,'—merely went to prove the partial liquefaction of the steam, *i.e.*, existence of elastic particles in the

'sheaf.' The 'state of rotation' of these spherical particles—absolute not relative—was noted, incidentally, as one of the phenomena; no inference being made therefrom. The term vortices, implying rotatory motion at the moment of the collision of the two jets—used for brevity and lack of a better—applied only to the irregular motion at the moment of forming, but ceased to be applicable to the 'sheaf' once formed and onward motion established in the 'lance.' The phenomenon of the two jets of steam and water when issuing from the convergent tube, or 'lance,' being still vapour and water and not yet converted into one jet of liquid water, had been, throughout the discussion, ignored. Injection, however, had never yet been observed to take place, when the 'sheaf,' at its escape from the 'lance,' had the density of liquid water. Moreover, during injection, the sheaf appeared dead-white like milk, more or less opaque, according to the proportion of vapour it contained, but, never transparent, like liquid water. This phenomenon of injection not taking place when the two jets, in their passage through the 'lance,' were converted into one simple liquid jet, had been reproduced by M. Turck, by means of a force-pump throwing a jet of water through the 'lance' with a pressure of 4 atmospheres against that of 1 atmosphere in the boiler. Notwithstanding this difference of 3 atmospheres in favour of the jet from the 'lance,' and against that tending to issue from the boiler; 0·99 of the former escaped by the overflow-pipe. From this it appeared that the action of one liquid jet encountering another, gave a resultant not in the direction required for getting into the boiler. The reason, in addition to this, of injection not taking place would appear to be that the 'sheaf,' not getting speed enough out of the steam therein condensed, a certain quantity must be added, which, by reason of the increase of temperature produced in the sheaf by the steam therein primarily and wholly condensed, would be only partly condensed. The non-condensed part, then, having kept nearly its initial velocity, to be given out hereafter to the water which enveloped it,—the velocity of the sheaf was thereby increased, till its quantity of motion became superior to that with which the water from the boiler would, if unopposed, issue. It was stated in the Paper, that when injection took place the dynamic effect in the sheaf was more or less converted into static effect according to the quantity of elastic matter held in each transversal element. For the purpose of trying to explain the phenomenon, the sheaf might be regarded as composed of so many elastic atoms wedged between non-elastic atoms, as it was known to be made up of liquid particles separated by steam particles; or, each successive transversal element, or section thereof might be imagined to be alternately non-elastic and elastic. In this way, the first section of the 'sheaf' would pass the throat of the injector with a shock, the effect of which would be to

compress that section which separated the third section from itself, and give out the velocity of that second section to be absorbed by the first. The fifth section would then, in like manner, compress the steam-buffer which separated it from the third, giving out the dynamic effect of the fourth section in static effect to the third, to be added to that quantity which already existed in the first section, and so forth, until the sum of these effects represented the total energy of the sheaf, or, in other words, its velocity diminished, whilst its pressure increased till it became greater than the back-pressure, and injection took place. If the steam-buffers were removed, the sheaf acted like a projectile, and when its velocity was greater than that imparted to it by the steam therein wholly condensed, it would raise the back-pressure valve intermittently, but not at all if its velocity were equal to that and no more. Injectors for very low pressure were made, in which, after producing a combined jet in the usual way, a certain quantity of steam was added to augment the velocity. But no Injector had yet been made which could do its work by means alone of the steam condensed in the sheaf, which must contain a certain quantity of non-condensed steam; the consequence of which was, that its density was no more, when injection took place, than one-half that of liquid water.

Mr. England could not conclude without again acknowledging the valuable contributions rendered to this Paper by M. Turck, who remarked that there were few instruments which had given rise to so many speculative opinions as the Injector had done; and the greatest *savants* had, in the first instance, been furthest off from the real state of things. One must have worked a long time with the Injector itself, and thereby observed the phenomena produced by its action, to be thoroughly aware of what took place. The phenomenon then, negatived in the discussion on this Paper, might be with confidence affirmed as actually taking place; while its explanation must be classed with those speculations here and there made, *i. e.*, subject to the fallibility which even the most scientific, on either side of the Channel, were liable.

February 21 and 28, 1865.

JOHN ROBINSON M'CLEAN, President,
in the Chair.

The discussion upon the Paper, No. 1,128, "On Giffard's Injector," occupied both evenings, to the exclusion of any other subject.

March 7, 1865.

JOHN ROBINSON M'CLEAN, President,
in the Chair.

The following Candidates were balloted for and duly elected:—THOMAS JOHN BEWICK, BARNARD WILLIAM FAREY, WILLIAM ROBERT GALBRAITH, and HENRY MONTAGU MATHEWS, as Members; JAMES JOSEPH ALLPORT, STEPHEN CHARLES BEST, JOSEPH FRANCIS DELANY, JAMES STAATS FORBES, WILLIAM THOMAS LEWIS, HENRY LOVATT, THOMAS BEEBY MOSELEY, THOMAS SAVIN, WILLIAM SCOTT SMYTH, FREDERICK MINSHULL WEEDON, and GEORGE WILSON, as Associates.

No. 1,126.—"An Account of the Drainage of Paris."[1] By HENRY BURDETT HEDERSTEDT, Assoc. Inst. C.E.

BEFORE describing the modern system, the Author considers it desirable to allude briefly, to the manner in which the drainage of the city was effected previous to the year 1808, when the subject first received thorough investigation.

The city of Paris being situated wholly within the valley of the Seine, that river naturally became the receptacle for all the sewage. The first mention of a drain was in the records of the year 1412, when the brook, or ditch of Menilmontant is referred to as having been used for that purpose. Menilmontant, from which the brook derived its name, was at that time an independent village, but at present it constitutes part of the north-eastern portion of the city, which, at that period, occupied the two small islands called respectively St. Louis and Nôtre Dame, and extended as at present, but over a lesser area, along both banks of the river.

The configuration of the portion of the valley of the Seine occupied by the city is as follows:—The left, or southern bank, presents an even and almost unbroken slope. The right, or northern bank, has one slope bordering on the river; and beyond the summit ridge of that slope, there is a dip in a northerly direction towards the brook of Menilmontant. This brook, in the first portion of its length, takes a westerly direction, and then, travelling to the south-west, finally falls into the river at Chaillot, some distance to the westward of the city. It was formerly called the

[1] The discussion upon this and the following Paper occupied portions of four evenings, but an abstract of the whole is given consecutively.

'great drain,' and in its course received the drainage of the streets of the northern slope of the right bank. The drainage of the southern slope was effected by means of gutters, which were carried along the streets directly to the river. Hence the 'great,' or main drain of the city was only a large natural ditch. Before the period between 1600 and 1630, no artificial drain appears to have existed. Some small works were then executed at Ponceau (now St. Denis North). Until 1740, no improvement was made in the ditch of Menilmontant. It was then, in the first instance, walled on both sides, and left open on the top, but a short time afterwards it was arched over.

From 1740, little was done until 1808, when the subject received a systematic investigation, the result of which was the commencement of a new drain in the Rue St. Denis, and the lowering of the inverts of the drain at Ponceau. The total length of work then executed was 1,533 mètres, comprising 491 mètres of alteration of the old drains, at a cost of 136,042 francs, and 1,042 mètres of new work, at a cost of 543,451 francs. Between 1808 and 1832, several new drains were undertaken. Of these, the principal are enumerated in the following Table :—

Date.	Place.	Length.	Cost.
During		Mètres.	Francs.
1812	New drain in the Rue du Mail	574	148,334
1812	New drain in the Chaussée d'Antin	480	103,006
1813	New drains from five slaughter-houses; *i.e.*, Popincourt, Montmartre, Monceau, Grenelle, and Villejuif .	3,585	..
1813	New drain at Montmartre	1,270	..
1820	New drains in the Rue Richelieu and Rue Neuve des Petits Champs	778	203,007
1821	Arching to the remaining portion of the great drain in the Rue des Gourdes	257	26,680
1825 to 1828	Side drain and branches at the Canal St. Martin .	4,230	..
1829	New drain in the Rue du Bac	1,327	166,158
1829	New drains in the Rue St. Benoit, Rue du Four, and Rue du Cherche Midi	1,109	139,260
1830	New lower portion of the new drain in the Traversière St. Antoine, having its outlet in the Seine . . .	104	31,243
1830	New drains for the Halles, in the Rue de la Ferronnerie, Rue des Bourdonnais, and Rue de Thibutondé	1,040	132,608
1831	New drain in the Rue de Buffon, from the Rue Esquirol up to the Rue Censier	530	48,287

In 1832 the dreadful ravages made by the cholera, disclosed the absolute necessity of cleansing and draining the streets, upon a better system than that which then prevailed. Up to the beginning

of 1833 there was no detailed plan of the small drains, nor any trustworthy levels. In fact, all useful and necessary data were wanting. Between 1805 and 1812, a classification of the drains then in use was made, which comprised a record of their sizes and lengths. The inspection of drains in those days was always unpleasant, as they were often either only partially cleaned, or not cleaned at all, and in some instances the duty became positively dangerous. In spite of this, a thorough examination and measurement of each drain was made by the Engineer-in-Chief in person. In 1833, a considerable sum was voted, for the purpose of obtaining a record of the plans and levels of the streets and drains then built, and an accurate survey was completed on a scale of $\frac{1}{144}$. This preliminary inquiry showed how impossible it would have been, without such help, to have planned and executed the new works then commenced. These comprised, in certain cases, the modification, or improvement of the old works, either by a change of level, or by the method of receiving the surface-water underground by means of openings in the side, instead of in the centre of the street. This last change involved the conversion of concave, into convex surface roads, thus adding practically (though in only a slight degree) to the width of the road.

In arranging the plan of outfall, it was necessary to study the surface levels of the streets, with a view of adjusting, or dividing the works into areas, or boundaries, dependent upon natural slopes, valleys, or basins. It was assumed that the drains should empty themselves into the River Seine, as far as possible, following the undulations of the several streets in a more or less direct course. On the left bank, where the city occupies an almost uniform slope, the drains of the several streets discharged directly into the river, independently of each other. In the present system they are ultimately connected by a transverse sewer, parallel with the river. The islands of St. Louis and of Nôtre Dame discharge their surface water by drains, communicating directly with the river, on each slope. On the right bank, the case is different. There is a southern slope, down which the drains passed into the Seine; and, as before noticed, beyond the ridge, there is also a dip in a northerly direction into the valley of the Menilmontant ditch. This 'great drain,' received the whole of the drainage from the slope on its right bank. The ridge of this slope occupied a line within the present fortifications, and from this ridge descended another slope in a southern direction, and now termed the 'extra mural,' from the fact of its lying beyond the present fortifications. The drainage of this surface can, if necessary, be placed in connection with the river on the north of, and beyond Paris.

There are five principal divisions, or classifications, of the several drains, as follows:—

1st. The left bank.
2nd. The Isles of St. Louis and of Nôtre Dame.
3rd. The right bank, southern slope.
4th. The right bank, northern slope, and,
5th. The extra mural.

The fourth, properly speaking, embraces the two slopes, forming the valley of Menilmontant, or the track of the 'great drain.'

Before commencing the new works, the principal features of each drain, or series, were arranged in a tabular form (Appendix I.), giving not only an account of the drain, but of all the fittings in connection with it. In some cases, a single line of drain extended over two, or more slopes, and had, in consequence, one culminating point or more.

The Seine is subject to heavy floods, but fortunately they are of rare occurrence, as during the past two hundred and sixteen years, commencing in 1658, there are but nine on record. At this date, the surface of the river rose 8·8 mètres, or 28½ feet, above its ordinary level. In 1802, when the last occurred, the river rose only 2 mètres, or 6½ feet, above the level of the discharging mouth of the modern drain at Asnières. These floods were all more or less disastrous, sometimes extending over fourteen days, and submerging large areas of the city. To check their recurrence, as far as possible, most of the low portions of the streets lying along the banks of the river were raised and walled in, to a point above the level of the flood of 1658. There are, however, some parts of the city still exposed to the effect of floods, but their results are much less disastrous than formerly, from the efficiency of the new drains, which carry off all flood-water almost as soon as the river level can subside, instead of leaving it to be absorbed, or evaporated, as when no drains existed.

Up to 1663, the total length of drains of all kinds was 10,380 mètres; up to 1806, 23,530 mètres; and up to the commencement of 1832, 40,332 mètres, of which only 36,736 mètres were allowed to remain; while 3,566 mètres were destroyed, or adjusted to the system then put in operation.

In 1832 the impetus given to the work may be judged of from the fact, that in January 1837, the total amount of work executed had increased from 40,302 mètres to 76,565 mètres.

The following is a detailed statement for 1837 :—

On the left bank of the river . . .	18,004·09
Two islands	796·82
Right bank, southern slope . . .	31,308·69
„ northern „ . . .	23,126·59
Extra-mural works	3,329·16
	76,565·35

In addition, further drains were projected

On the left bank	6,513·00
Two islands	24·00
Right bank, southern slope . . .	6,585·50
„ northern „ . . .	2,960·50
	16,083·00

There were also twenty-two distinct new works under consideration and prepared for, although not determined upon, increasing the 16,083 mètres to 20,000 mètres, making a total length of upwards of 96,000 mètres.

The position, cost, and special object of the construction of these several drains, and the difficulties that were encountered and conquered in bringing them to a successful termination, will now be noticed. During 1832, the works embraced thirty-three distinct streets, and involved the lifting of 104 mètres' length of a drain in the Traversière St. Antoine (right bank). Until then, this street had only open drains, or gutters, along the edges of the roadway. The foundation of this drain was liquid mud, and a large sum was spent in pumping water from it. The thirty-three works were of a total length of 15,008 mètres, and cost 2,158,131 francs, or about £5. 13*s.* per lineal mètre. The first drain executed by tunneling was in the Rue Bar du Bec, 150 mètres in length. The side-walls were built of masonry, the arch being in brickwork. This work cost 200 francs, or £8 per lineal mètre. The Bièvre, a short, dirty, and small ditch, was walled in, on both sides, for a portion of its length. By this, some swampy land was reclaimed, and its exhalations rendered less offensive.

The works of 1834 were of the same kind as those just noticed, and the rate of progress was about the same. They extended over twenty-eight streets, for a total length of 6,810·31 mètres, costing 661,006 francs, or £26,440, or £3. 17*s.* 6*d.* per mètre. New drains were built, high enough to admit of their being cleaned from the inside. To effect this, it was necessary to alter the surface-levels of some of the streets, so that the drains should not project into them. In former years, the streets were built first, and the drains became a subsequent consideration. At the present time, the conditions required for the proper working of the drainage are first determined, and the street is made in accordance therewith.

In 1835, twenty-two new works were completed (including alterations of existing drains), of a length of 8,713 mètres, costing 803,511 francs, or £32,140, or £3. 13*s.* 9*d.* per lineal mètre.

In 1836, the outlet into the Seine, from the Rue de Bourgogne

(south side) was much improved, and the original mouth was abandoned. In the Rue Lafitte, and at the foot of the Rue des Martyrs, a new drain was built, to carry below the surface of the road all the rain-water which previously poured in torrents down the Rue du Faubourg Montmartre, lying immediately below it. The difficulties met with in the execution of this drain were very great. In the first place, it was necessary, for some distance, to sink it at a depth of 5·9 mètres, or 19 feet 2 inches below the surface. This was done in open cutting, in the lower beds of which the soil was semi-fluid; and, in the second place, there were most offensive exhalations from the foundation. This drain was carried below that in the Rue des Martyrs, and, at the point of crossing, a large cast-iron pipe was used.

In many places, new drains were built, and these necessitated the alteration of several streets. In that part of the work between the Seine and the Faubourg St. Honoré the greatest depth of open excavation was 7·5 mètres, or 24 feet 4 inches, and before reaching this depth quicksands were met with. It might, no doubt, have been arranged to alter the level of the drain, so as to avoid part of this difficulty; but, as the thorough drainage of the streets in the north-west quarter of the city depended upon its construction at the level originally contemplated, the excavation was persevered with, and the drain completed. The rate of progress of this most difficult work was a little more than 8 lineal mètres per day.

The works hitherto enumerated may be taken as a fair example of what had to be done in the effective drainage of the city. It will have been remarked, how often it was necessary to alter the levels of old drains, to admit of their communication, one with another. This shows the value of the detailed survey and levels of the city, which were taken in 1833. Another feature of these alterations is the adjustment of the roadway surface, so as to accommodate drains of minimum height.

With regard to the conversion of the concave surfaces of roads into convex, it may be shown to have formed an important part of the drainage system. Against hollow roads, there were always complaints. The old plan constantly cut up the roadway with cross channels, or gutters. Another object, however, had been considered in making the change—the certainty of freeing the roads more readily from rainfall. In the concave roads, iron gratings were set on the top of small working shafts, built on the crown of the drain-arch. These iron gratings frequently became clogged, and the passage of the water was impeded to such an extent, that raised planks were occasionally used, to enable foot-passengers to cross the road, the vehicles meanwhile being compelled to travel through a swamp of mud. The old roadway had, in many places, to be lifted, to obtain sufficient headway for

the minimum-sized drains; the value of the convex roads, as affording an extra height, is therefore obvious.

The new sewers differed from the old in two respects: first, in the use of a much larger, though not more effective, area; secondly, in the use of footpaths, and of rails for carrying wagons. No rule seems to have been established by which to determine the form of the old sewers, or drains, though it was arranged, where possible, to give a clear height of 1·8 mètre, or 6 feet. This was to make the cleansing as little unpleasant as possible to the workmen engaged, as it was supposed that the work, on that account, would be carelessly attended to. When this height of 6 feet could not be given, it was recommended to keep the working-shafts close together, so as to allow the workmen occasionally to stand upright; but a rigid adherence to this minimum size would, in many cases, have compelled the Engineer to relinquish many other good points. The minimum inclination allowed in the new drains is 1 in 1,000. Numerous instances occur, in which the inclinations are much steeper, and in dealing with these, it has frequently been arranged that the flooring should be disposed in steps at intervals, especially at the points of junction with other drains. Working-shafts were provided, covered with cast-iron traps, large enough to admit of the easy descent of a man by a ladder. These were placed directly over the centre line of the drain in the old system; and at the side of the road, in communication with the main drain, by a short transverse channel, in the new one. In some of the drains built prior to 1832, the masonry was of an expensive character, ashlar-work having been constantly resorted to; the lime used for the mortar, however, was not specially selected. Subsequently, none but good hydraulic lime has been used, and with it a class of random rubble-work, which, judging from the test of several years' wear, has answered all expectations.

The Author is unable to trace satisfactorily, from the sources at his disposal, a continued account of the annual progress and expenditure of each work subsequent to 1837. The following statement, however, shows the total length executed, the date of construction, and the cost of the works subsequently to the year 1855:—

Date.	Mètres.	Cost in Francs.
1856	3,527	668,563
1857	10,950	2,571,045
1858	4,836	597,271
1859	18,435	5,379,438
1860	..	3,625,242
1861	20,079	..
1862	30,057	4,970,679

Up to the end of 1863, there were in operation 350,000 lineal mètres, or 217 miles. Comparing this with the 76,565 mètres at the beginning of 1837, it will be seen, that the length has been more than quadrupled in twenty-six years.

Before the introduction of the mechanical contrivances now in use, several drains were laid at an inclination of 1 in 1,000, an insufficient slope for carrying off, in suspension, all the solid material of the drainage. Cleansing then, where attended to, was done by hand-labour, assisted by flushing: rakes, or scrapers of wood, cut to the contour of the invert, were worked backwards and forwards, until all the mud had been drawn to a point under one of the working-shafts, through which it was lifted. This arrangement was chiefly confined to the small class of drain. In the larger ones, the brush and rake were still made use of, but assisted by a shutter, turning on a horizontal pivot, or spindle, on the upper edge, and lying across the drain. This shutter, being retained in a vertical position by the back pressure of the water, acted as a dam, and on a sufficient head being obtained, it was opened, and the rush of the water carried all before it. Originally, this shutter was worked exclusively from the inside, but it was afterwards attached to chain gearing, which enabled it to be worked from above, by a man stationed at the shaft over the centre of the drain.

The preceding description will show, that there was a decided difference in the features of the old, and of the new systems. Under the old system, the river itself, within the limits of the city, was made the main receiver of all the sewage. From both banks, and from the central islands, all outlets poured directly into it, and at the end of 1837, there were probably forty independent mouths. Under the new system, with three exceptions, all these discharging heads were abandoned, and longitudinal drains of a large section, running parallel with the river, have been substituted. There are at least four discharges into the Seine, namely Asnières, Chaillot, the Isle St. Louis, and the Isle Nôtre Dame: three of these are in the city proper. On the left bank of the river, a drain of the largest size in use empties itself (as a temporary expedient), through an old drain of a much smaller size, into the river near the Pont de l'Alma. On the right bank, a large drain discharges at Asnières, quite clear of the city.

The provision for the discharge of the household water and of the rain water is made as follows: All roof water is collected in gutters along the tops of the houses, and is carried down by ordinary cast-iron piping. At the level of the pavement, it is received into iron troughs of rectangular section, about 4 inches square inside, and having an open central groove, about 1 inch in width

along its upper surface. These pipes are flush with the pavement, and extend to its edge, where they discharge into the side gutters, which have water openings, or mouths at intervals, and these openings conduct the water into a small tunnel. It has lately been determined to continue the pipes from the faces of the houses to the branch drains. The household water is in like manner to be led into the back, or end of the branch drain, by cast-iron piping, so that in future the pavements will be free from any other water than that which actually falls on them. A decree, passed in March, 1862, requires all householders to carry off water in this manner; but this order has not yet been entirely complied with, probably because the authorities are too much engrossed with new works to look to the alteration of the present system, which would involve the immediate construction of large numbers of branches.

Night-soil has no connection whatever with the drains, except in a case which will be presently mentioned. Most of the houses in Paris are built in blocks, having a central court yard common to all, and in this is usually found the cesspool, or fosse d'aisance, which receives the soil, and is emptied at intervals. This operation, offensive as it may at first sight appear, is carried out almost entirely without unpleasant smell. The exception alluded to occurs, where in some parts of the city, at barracks chiefly, a new system is under trial. The plan consists in leading the night-soil by pipes from the houses, to the branch drains, where it is received into cylinders perforated with fine holes, which allow the liquid portion to rise in an outer cylinder, while retaining the solid matter within. The liquid portion is drawn off, day by day, and at intervals the internal cylinder is emptied of its contents.

In all cases, the night-soil is carted away from the city, and is deposited in appointed places. A certain proportion, as much as finds a ready sale, goes to deodorising works, and is converted into manure; but large quantities are still wasted.

Sand is stored in heaps along the roads, to be spread over the surface whenever puddles are formed. The slightest fall of rain at once converts this material into a mud, which, with the road-scrapings, is not uncommonly swept into the drains. In many cases the inclinations of the drains are so slight, that they can hardly carry away the solid matter in suspension, and it becomes necessary to cleanse them. The means for effecting this operation will now be noticed. The drains not having a separate waterway provided for them, are cleaned by hand. The removal of the mud through the shafts is performed between 11 P.M. and 8 A.M., by gangs of ten men, who frequently employ four carts, so that about thirty carts are in this manner kept in constant work.

When the waterway forms a distinct part of the drains, they

are all cleaned on one principle, but by mechanical appliances, differing in their details according to the size of the drain. These appliances will now be noticed. For the larger sizes, a cleansing boat is used, furnished with a large scraper, at its bow-end; this scraper nearly fills the section of the waterway, and is capable of motion in a vertical arc. It can, therefore, be raised, or lowered till it touches the invert. On commencing operations, the scraper is lowered by means of crab-gearing, till its edge dips into the mud; it then forms a dam, behind which the water gradually rises, and affords a motive power, which pushes the boat forward, carrying the mud with it. On the water rising in the drain, the boat also rises, and lifts the scraper, which requires constant adjustment, so as to be kept in contact with the mud. This operation is not, therefore, so simple as it would appear at first sight. The difficulties connected with it will be understood, if it is considered, that were the scraper a solid disc, closely fitting the sides of the waterway, it would completely dam up the backwater, and though it would thus receive a great impulse, on the other hand, in a short time the mud would accumulate in front, and create a resistance too great to be overcome by that power. The boat might, however, in time, rise over the obstacle, but it could not remove it, and the apparatus would thus be useless. To obviate this, the scraper is perforated with three openings, of which the central one is always open. Those at the sides are fitted with sliding shutters, like lock-gate sluices. They are opened by hand, and are retained in position by a small chain, of which the links drop over a stud on the top of the scraper. The constant passage of water through the spaces between the rim of the scraper (when in position), and the sides of the waterway, and the apertures, creates so violent an agitation in front, that all solid matter is held in suspension, and driven forward with the progress of the boat itself. When this natural action is further assisted by men preceding the boat, and stirring up, and loosening any sediment, the working of the boat is generally pretty certain, although slow; but in a short time, the water comes to one level, both in front of, and behind the scraper, when all motive power is lost, except that due to the current. No cleansing can now be effected, and the side openings of the scraper must be closed, to allow another head of water to accumulate. If the resistance to the progress of the boat be too great, with the scraper at full depth, it must be raised, so as to skim only, instead of cutting, as it were, a larger quantity of sand, or mud. In this manner, the boat may have to travel twice, or oftener, over the same length of work. It frequently happens, during the dry summer months, that there is a great deficiency of water, and the boats therefore cannot be brought into successful operation without assistance. This is afforded by the use of dam-boards, of which

there are five, along the large drain on the right bank of the river. These fit the waterway exactly, are not perforated, and (when not in use) are slung overhead, on a frame of wrought iron. When lowered into the water, they are retained in a vertical position, by means of chains, connecting the lower edges with the side-arms of the frame. These chains are so adjusted, that when the frame is flush with the footpath, the dam-board is erect, being kept in position by the pressure of water acting against the tension chains on the top and bottom edges. By the use of two of these dams, sufficient water may be collected in any spot for the working of the boats. There are fifteen dams on both sides of the river. The old dams were of wood, but all new ones are of iron. They are raised and lowered by small crabs, placed either in the extrados of the arch, or built in small recesses at the side, at the level of the footpath, and connected with the dam framing by guide pulleys, arranged along the side and roof of the drain. Both plans are effective, but the latter is preferable, as the former can only be resorted to in the case of chambers (to be mentioned hereafter) being attached to the drain.

The manner in which the cleansing boat is kept true to the axis of the channel, is as follows: at the stern, there is a gun-metal screw, working in a wrought-iron frame, and raising, or lowering a wrought-iron cross head, carrying two movable wooden tail-pieces fitted at their extremities with cast-iron rollers, which are kept in contact with the sides of the waterway, by means of two side-rods, which can be pinned down in any position within a moderate range. On the top edge of the boat framing, are folding steps for getting into, or out of the boat, which is also fitted with a long box on each side, forming seats for the workmen, and receptacles for the tools.

These boats, both for large and for small drains, are attended by three men, who work the scraper and hand tools, and further employ themselves occasionally in towing, if the progress is unusually slow. Under the most favourable circumstances, it seldom happens that more than 800 lineal mètres can be thoroughly cleansed in a day, owing to the necessity for going over some places several times.

Some of the smaller drains are cleansed by a small truck, which is used with an apparatus like that of the boats. It is fitted with a scraping board, moving on a horizontal shaft below the truck frame, and geared to a crab above, by chains in the front and the rear. The scraper is lowered into the water, and the cleansing goes on as in the boat, dams being fixed at intervals of 600 mètres. The boats work only down stream, but are capable of moving in either direction. It often happens that they have to cross a drain in their way to other parts of the town. In such

cases portable rails are used, spanning the cross drain, and fitting into grooves in the footpath. All drains with trucks have the waterway plated with 3-inch angle iron, serving the purpose of rails.

In addition to the appliances hitherto mentioned, there was at one time in use a machine which may be termed a travelling circular rake. It consisted of a horizontal shaft, mounted on a truck frame, travelling on the rails; this shaft carried knives, or blades, at right angles, and projecting to the level of the bottom of the drain. The shaft was put into revolution by crank handles, and the knives getting entangled with the solid matter of the sewage, tore it up, and left it in a state more easily dealt with by the cleansing wagon, which followed a short distance behind. The shaft, with its knives, was at right angles to the line of drain along which it travelled. This machine does not appear to be much resorted to now.

In some of the drains, the mud is at once removed through the side shafts, or else it is transported to the river in tip-wagons, two places being appointed for its discharge. The only peculiarity in the wagon, is the manner in which the wheels are connected with the body. The central tie, or rather brace, serves to keep the main timbers in position, and, at its extremities, it branches off at right angles, and forms two short pins, upon which the wheels turn. The overtipping of the wagon is prevented, by the framing coming in contact with the cross shaft, or brace, by which it is supported. The pivot, upon which the body of the wagon turns, is at the side, instead of at the bottom, as in wagons employed in the transport and rapid discharge of earth. The tip wagons accompany the gangs of workmen along the length of the drains. They are filled, and run out to the two tipping heads, one of which is on the north bank of the river, at the Place du Châtelot, the other on the south bank, at the Quai St. Michel. In one case, the unloading is performed by hand, in the other, the tipping is one of self-action. In both cases the mud is received by barges of 30 cubic mètres capacity, moored alongside, and provided with shoots. The necessity for cleaning the drains does not seem to be recognised till the deposit of mud accumulates to about 4 inches, or 5 inches in depth.

If, during the hot summer months, it is difficult to work the boats, from a scarcity of water, it is not so in winter, when arrangements come into action for preventing mischief from too great a quantity. During heavy rains, the whole system of drainage is in full operation, and discharges large volumes of water into the main tunnels, on both sides of the Seine. In order to provide for the safety of the workmen, in the event of their being overtaken by a sudden rise of water above its normal

level, safety chambers have been built in the roofs of the drains. This plan can only be carried out in places where there is ample headway, and advantage is therefore taken of this as often as possible. The chamber is reached by an opening in each of the side walls of the drain. Iron bars are built into the wall, from which they project about 6 inches, forming a ladder, and steps of masonry are constructed, commencing at the crown of the arch of the side branch tunnel, and communicating with the extrados of the arch of the drain. On the south side of the river, along the course of No. 3 drain, the want of headway has prevented the construction of any of these chambers, and working shafts have been constructed instead, to enable the men to reach the street itself.

In June 1855, and July 1860, the water rose, in the outfall drain of the right bank of the Seine, to a height of 4 feet 11 inches above the level of the footpath, and in that of the left bank it rose 7 feet above. Since then, many overflow weirs have been built along the main receiving drains which run parallel with the river, so as to carry off surplus water, after it has risen above the footpaths.

The particular section of drain adopted depends at present on local circumstances; and in proportion to the amount of sewage received from several confluent sources, the size is increased, until at last it assumes the dimensions and importance of a main outfall drain, like that falling into the Seine at Asnières. Both in the ancient and in the modern systems, it has always been considered indispensable, that all drains should be high enough to allow of the workmen standing upright in them.

One feature of this system will at once present itself—the absence of small pipes, so constantly used in England. The smallest section ever built, under either the old or the modern system, was 5 feet 6 inches high by 2 feet 3 inches wide, at the springing of the roof. Now, seeing how small a portion of the total area is occupied by the waterway proper, the modern system appears extravagant, and particularly so in those cases where a considerable space is sacrificed for the accommodation of two water-mains.

Another source of heavy outlay arises from a recent Act, which compels all householders to build, at their own cost, private branches in communication with the street-drains; and, apparently with a view of lightening the pressure of this Act, it has been established that, in all new streets having a width of 22 mètres, or 72 feet, the town commissioners shall build a drain on each side of the street, so as to shorten the length of the transverse drains. In such cases the drains would be under the pavement, and the outlay which the householders would have to incur would be very trifling. This plan would certainly remove the drains

from the damaging effect of heavy traffic over them; but as the works are apparently substantially built, no such evil effects have yet been noticed as to make this point worthy of more than slight consideration. In fact, 72 feet seems a small width of street in which to compel the adoption of two drains.

As the water-works are connected, to some extent, with the drainage of the city, the Author gives the following details with regard to them. The mains vary in diameter from 3 feet 10 inches to 1 foot. There are eight establishments for supplying the water, of which the two principal are at the Quai de Billy, on the west, and the Quai d'Austerlitz, on the east of the city. At the former establishment, there are two condensing engines of 180 H. P. each, working solid plunger pumps, which force water to a height of 50 mètres above the summer level of the Seine. These engines lift 38,000 cubic mètres of water every twenty-four hours. At the Quai d'Austerlitz, there are two engines each of 120 H. P., which lift 22,000 mètres of water, and force it 56 mètres above the Seine. The reservoir in connection with the engines at the Quai de Billy holds 37,000 cubic mètres, and each of the two belonging to the Quai d'Austerlitz, holds about 10,000 cubic mètres. Another reservoir is being built at Menilmontant, which will contain 40,000 mètres, of which 25,000 cubic mètres will be received from the St. Maur works, and 11,000 cubic mètres from those of the Quai d'Austerlitz, which will then be forcing to a height of 73·75 mètres instead of 56 mètres as at present.

During the early part of 1864, when the Author was in Paris, he noticed the rapid progress of new works in several parts of the city; but in these no provision appeared to have been made for the branch drains, which, it might naturally be supposed, would be proceeded with simultaneously with the main drains. Irrespective of the inconvenience to the public of the opening out of a street twice, instead of once, it would entail the expense of a second opening, and the destruction of part of the main drain already built.

A project was lately under consideration for discharging the sewage, of both sides of the city, at Asnières, the point to which, at present, the northern sewage only is conducted. It was proposed to effect this by means of a syphon under the river, connecting the two principal drains at a point close to the Pont de la Concorde, and thence carrying everything up to Asnières by the outfall sewer. Another plan consisted in having the syphon placed in continuation of the existing temporary discharge mouth, at the Pont de l'Alma, and thence carrying a new line of drain into Asnières, a little higher up than the present outlet.

At the Pont de la Concorde, the left bank drain is said to be exactly 1 mètre above that on the right, and it was assumed that this would be sufficient to keep the syphon clear of all solid

deposit, and so maintain it at all times in proper working order. No details of this project could be obtained, and it appears to be abandoned, for a recent communication, from the Chief Engineer of the works, expresses the intention of at once extending the present drain along the left bank of the river up to the fortifications, outside which the sewage is to be discharged.

The outlet of the drain at Asnières is 6 mètres, or 19½ feet, below the point to which the heavy flood of 1658 rose. It is, however, sufficiently above the ordinary level of the water in the winter, to insure its proper action at all seasons.

The velocity of the Seine is not sufficient to carry off the heavy matter from the drains, and consequently mud accumulates in the river bed, which is cleared by dredging at an annual cost of about £3,200, being at the rate of from 10*d.* to 1*s.* per cubic mètre. It appears from this, that upwards of 60,000 cubic mètres of mud are annually carried into the river, notwithstanding the large quantities taken away by barges. The maintenance of the system is most expensive, having amounted, during a recent year, to about £30,000, including the pay of one inspector, two office-assistants, twenty general superintending conductors, and the labour of four hundred workmen employed in dredging the Seine, and in removing the deposit by carts and barges, as well as for tools and stores.

The drains below ground all bear the name of the streets above; thus all confusion about the position of any work is prevented, and Paris below ground is, as far as it goes, a counterpart of that above. The drains are approached by other entrances than the side shafts in the principal parts of the city. A commodious flight of steps leads from the pavement, which here consists of two large wrought-iron trap-doors, supported on wrought-iron girders. The places of rendezvous, seven in number, are also store-chambers, and are worthy of notice. The principal one is at the Place du Châtelet, on the north bank of the river. It forms a storeroom, overflow-weir, and mud-discharging head. In it are stored cleansing wagons, tools, and materials. On the top level, a line of rails commences, in continuation of that down the Boulevard de Sebastopol, and runs up to the river-wall, which it pierces, and at which the mud collected in the tip wagons is discharged by shoots, into barges below. The face of the river-wall makes an angle with the line of rails, of which each terminates exactly in the plane of the wall-face. As one rail does not stand out so far as the other, the wagon cannot be run out far enough to admit of its self-tipping power coming into play; and in consequence, it has to be unloaded slowly by hand. This might at once be remedied by producing the shorter rail, and supporting it outside the wall by a

light bracket. On this extension line of rails, and close to the drain crossing it, and running parallel with it, is a set of three turntables, for the convenience of wagons passing each other up to the tip-head. One of these turntables communicates with a line of rails running nearly parallel with the river, and forming a 'lay-by' of about 40 feet in length, upon which are kept several extra wagons. From the end of this line a small tunnel is prolonged, curving round till it comes out at the river-wall, at a point about 80 feet west of the discharge head. All this arrangement is on the level of the footpath of the drain running down the Boulevard de Sebastopol. From the end of this drain, and from the side of that into which it falls, a flight of steps leads to a gallery immediately under the line of rails from the Boulevard. This gallery being open on the river-wall, forms an effective overflow weir in case of storms, raising the level of the water in the drains. In addition to this, it also, at times, serves a purpose for which it was not originally intended; the reception of mud in large quantities, tipped into it from above, when the wagons cannot be emptied fast enough at the proper tip-head, owing to the objection already spoken of. The lower gallery is also built at a convenient level for receiving stores from barges.

At the Pont Nôtre Dame, a short distance to the east of that described, there is another chamber, remarkable for its size, rather than peculiarity of construction. It is about 100 feet long, 45 feet broad, and 15 feet high, and is covered by a segmental arch. It is entirely below the roadway of the quay.

At the church of Nôtre Dame des Lorettes, in a central position on the right bank of the city, there is another chamber, formed by the intersection of several drain roofs.

On the south side of the city there are two. One at the Quai St. Michel, the other at the corner of the Boulevards St. Germain and Sebastopol. The former is unquestionably the more important. From the point where No. 3 drain of the Boulevard runs into that of the quay at right angles to it, a line of rails commences in continuation of the Boulevard drain, and runs up to the river face-wall, at a short distance from which the single line of rails is increased to a double line, both projecting slightly over the wall, and having their ends turned up, so as to catch the wheels of the wagons, which are run up quickly, and instantly tipped into a barge below. In the Boulevard de Sebastopol on this side, as in the other, there are two drains; one on each side of the street under the pavement; and at intervals, small tunnels are constructed transversely, so as to admit of easy communication with either side. The chamber at the corner of the Boulevards St. Germain and Sebastopol, is a spacious vaulted room, with lockers for small stores and tools.

Close to the chamber of the Pont St. Michel, is a large public

fountain of the same name, discharging water into the adjacent drain, which is thus effectually cleaned. With respect to the whole of the drains at work, the Author can state, as the result of several inspections, that there is a complete absence of unpleasant smell.

Space is everywhere economised. Not only are the water pipes inclosed in the drains, but gas pipes also. This plan of laying the latter seems to be a great improvement upon that practised in England, where there is a frequent necessity for disturbing the road surface, to the great inconvenience of public traffic. In the French system, the pipes, being supported on brackets, are easily accessible, and being all tarred, they do not appear to leak. Should a leak occur, it would soon be discovered. So far as a few years' trial can show, the system has given perfect satisfaction. Besides gas pipes and water pipes, there are several lines of telegraph in the drains, chiefly in connection with Government offices.

Respecting the actual building of these works, in the first place, all earth displaced by the bulk of the drain when in place is carted away. Bricks have rarely been used either in the old, or in the new works. The old ones were of a rough random rubble plastered; of a superior kind, coursed; and of ashlar, chiefly for the inverts. Concrete was frequently employed in the foundations then, as at present, but the selection of lime for the masonry was, formerly, not considered important. At the present time, a coarse gritty sandstone, 'French Burr,' an amorphous description of quartz, is extensively used, set in the manner of random rubble. In this, the stone is of small pieces, entirely without beds, and does not form more than perhaps 40 per cent. of the bulk of the work. It serves to economise the employment of mortar, rather than to form the staple material of construction. The sand for the mortar is not sifted, but is used just as it is taken from the pit—coarse and fine together. In this manner, it is rather a concrete than a mortar: it is employed in a dry stiff state, and contains roughly bedded the stones, often smothered in mud. The use of water seems to be carefully avoided, except when the mortar compels a resort to it; but in spite of these objectionable features, the work is strong. Cracks are rarely met with, although the drains have to stand the jar of heavy traffic. The strength is doubtless attributable to the exclusive employment of good hydraulic lime in the mortar. In the rubble-work of all the smaller drains the internal and the external surfaces are invariably plastered with a good hydraulic lime-mortar, and in the larger, with Roman cement.

The drains in the Boulevard de Sebastopol, and in the Rue de Rivoli are of a different class of work, being built in sandstone-coursed rubble, and the face pointed, instead of plastered.

In the store-chambers, the work is a combination of both classes, of which the best is used in the roof arching. In these works the lime and cement employed come to a great extent from manufactories at Meudon and Boulogne, near Paris. The exteriors, of all arches, are first plastered, and then coated thickly with asphalte.

Within the last three years, a new building material (concrete, or béton Coignet,) has been introduced, which, it is believed, will supersede all others, and lay the foundation for a better and cheaper class of masonry. The immediate employment of this material, on an extensive scale, is, however, deferred by the Engineer, who declines to trust to a short experience, satisfactory as it has so far shown itself. This concrete is similar to that made use of in the drains, which is now about eighteen months old, and is exceedingly hard. It is composed of sand, or ballast, dredged from the Seine, mixed with hydraulic lime and Roman cement. The lime comes from several sources. The cement is chiefly from Meudon, Boulogne, and England. Among other tests of its quality it is required to weigh from 2,800 lbs. to 3,100 lbs. per cubic mètre. The proportions adopted in this mixture are: 5 mètres of sand, or river ballast, 1 mètre of hydraulic lime, in powder, and 6·88 bushels, or 250 litres of Roman cement. The whole is thoroughly incorporated in a pug-mill, with only as much water as will damp the mass, and enable it to cohere under pressure in the hand; and in this state it is at once used. As prepared for the drains, it costs 40 francs, or £1. 12*s.* per cubic mètre in position, but the varieties of mixtures make its cost fluctuate between £1 and £3. 5*s.* per mètre.

In building with this béton, the drain-foundations are accurately trimmed to templates of the desired section. Inside the excavation there are placed movable plank frames, corresponding in shape and position with the inside of the drain. The béton is poured in damp and disintegrated, and is immediately rammed down. As the work rises, the side-frames are carried up, and a length of about 20 mètres is frequently under construction at one time. The arch is built over a close-boarded, and smooth-planed centering, which, in common with all other frames, is withdrawn the moment the work is closed in. The internal surface then receives attention, and any irregularities are at once made good, by the addition of more béton, rammed in by hand. Subsequent plastering is not required; and, if carefully executed, the lining of the work is as smooth as that of the best rubbed ashlar. The materials set so rapidly, that in three days they will resist the abrasive action of running water.

A schedule of the rates paid for masonry, so arranged in a tabular form as to show the cost per lineal mètre of several varieties of drains (Plate 13), is given in Appendix II. A state-

ment of the current prices of the materials used in the construction of the works is given in Appendix III.

In conclusion, the Author would remark, that he has not been professionally connected with the works described. While making a short stay in Paris, in the early part of 1864, he obtained from M. E. Belgrand, the Engineer-in-Chief, permission to inspect them, and he has also to thank that gentleman for much valuable information. By these means, coupled with assistance from other sources, including that kindly afforded by M. Paul, he has been enabled to draw up the present Paper.

The Paper is illustrated by seven plans and drawings, from which Plate 13 has been compiled.

APPENDIX.

APPENDIX I.

Classification on Main Line and Branches.		Length of Drains.		Breadth of Drains.		Height of Drains.		Inclination per metre length.	Offsets for Shafts and Water-entries.				Enumeration and position of		Number of			Remarks.
									Levels of invert-surface.						Traps and Shafts.	Water mouths.	Gratings.	
Datum points on the Main Line.	Branches connected with the same Sheet of Plans.	Main Drain.	Branches.	At springing line.	At invert level.	At the intrados.	Total depth below surface of Street.		Shafts.	Water mouths.	Shafts.	Water mouths.	Traps and Shafts.	Water-entries and Gratings.				
Totals of details . . .																		
Grand totals . . .																		

DETAILED COST per lineal mètre of DRAINS of the several Sections shown in Plate 13, in Sandstone, Rubble Masonry, set in Cement Mortar.

The cost of Rails is not included.

—	Reference.	Cost of Unity.	Section No. 3.		Section No. 5.		Section No. 6.		Section No. 6A.		Section No. 8.		Section No. 9.		Section No. 10.		Section No. 12.	
			No.	Cost.	No.	Cost.	No.	Cost.	No.	Cost.	No.	Cost.	No.	Cost.	No.	Cost.	No.	Cost.
				Francs.		Francs.		Francs.		Francs.		Francs.		Francs.		Francs.		Francs.
Excavation—filled in	1	1·45	3·02	4·37	2·34	3·39	2·04	2·96	2·04	2·96	1·63	2·36	1·22	1·77	1·07	1·55	0·75	1·09
,, carried away	2	4·25	18·27	77·64	14·30	60·89	11·05	46·96	11·94	50·75	8·17	34·63	7·03	29·88	5·28	22·44	4·17	17·72
Side planking	3	..	4·86	4·86	4·98	4·98	4·07	4·07	4·71	4·71	3·71	3·71	3·53	3·53	3·08	3·08	2·91	2·91
Shoring	4	14·00	0·69	8·40	0·40	5·60	0·24	3·36	0·27	3·78	0·15	2·10	0·12	1·68	0·09	1·26	0·07	0·98
Lifting, and resetting of pavement	5	1·20	5·10	6·12	4·00	4·80	3·43	4·12	3·43	4·12	3·04	3·62	2·62	3·14	2·31	2·77	1·84	2·20
Masonry in rubble	6	35·00	5·12	179·20	4·60	161·00	3·94	137·90	4·17	145·95	2·43	85·05	2·05	71·75	1·45	50·75	1·36	47·60
Plastering with coat $\frac{3}{4}$ inch thick	7	2·95	8·14	24·01	7·80	23·10	7·00	20·65	7·00	20·65	6·30	18·59	6·00	17·70	5·60	16·52	5·40	15·93
Plastering of water-way and foot-paths	8	4·60	5·26	24·20	3·82	17·57	2·84	13·06	3·54	16·28	1·70	7·82	1·82	8·37	1·00	4·60	0·55	2·54
External plastering	9	1·80	7·67	13·80	5·94	10·69	5·15	9·27	5·15	9·27	4·56	8·10	4·05	7·29	3·50	6·30	2·80	5·04
Centering	10	..	..	7·50	..	6·00	..	4·50	..	4·50	..	4·50	..	3·00	..	3·00	..	3·00
Post and hand-rail barriers	11	..	..	1·30	..	1·30	..	1·30	..	1·30	..	1·30	..	1·30	..	1·30	..	1·30
Trimming of excavation	12	0·04	9·48	0·38	9·76	0·39	8·26	0·33	9·06	0·36	7·76	0·31	7·28	0·29	6·74	0·27	6·48	0·26
Price per mètre, where the road is paved	..	..	..	351·78	..	299·71	..	248·48	..	264·63	..	172·09	..	149·70	..	113·84	..	100·57
Price per mètre, under a macadamized road	..	..	..	345·66	..	294·91	..	244·36	..	260·51	..	168·47	..	146·56	..	111·07	..	98·37

NOTE.—In the above Table a depth of excavation has been assumed, as under, for the several drains; the value being expressed in mètres.

For Section No. 3, 4·74. No. 5, 4·83. No. 6, 4·13. No. 6A, 4·53. No. 8, 3·65. No. 9, 3·63. No. 10, 3·24. No. 12, 3·24.

The cost in all the columns is expressed in francs, of which 25 are equal to £1. The difference between the two total costs of each drain is arrived at by deducting from that for the paved road, the sum set against the lifting of the pavement, which does not, of course, apply to an estimate for a macadamized road.

Reference No. 1, unity represented is 1 cube mètre excavated and thrown to top of cutting; and subsequently thrown back and well rammed in.

,, ,, 2, ,, ,, ,, ,, removed from side of pit, and carried by carts to appointed places at a distance.

,, ,, 3, ,, ,, 1 square mètre fixed in place.

,, ,, 4, ,, ,, 1 cube mètre of timber in position for any temporary purposes.

,, ,, 5, ,, ,, 1 square mètre lifted and piled in the first instance; and subsequently returned to position, and set on a bed of sand not less than 4 inches deep.

,, ,, 6, ,, ,, 1 cube mètre of work set in mortar of 1 part of Portland cement, and 4 parts of sand.

,, ,, 7, ,, ,, 1 square mètre of mortar, of equal parts of hydraulic lime and fine sand, laid on $\frac{3}{8}$ inch thick.

,, ,, 8, ,, ,, ,, ,, ,, similar to the preceding, but laid on $\frac{3}{4}$ inch thick.

,, ,, 9, ,, ,, 1 square mètre.

,, ,, 10, ,, ,, 1 mètre length of cutting, valued according to its diameter.

,, ,, 11, ,, ,, ,, ,, posts and hand-rail, temporarily fixed, and taken down again.

,, ,, 12, ,, ,, 1 square mètre of trimming.

APPENDIX III.

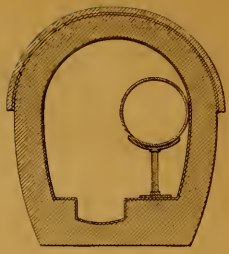
PRICES of some of the MATERIALS employed in the CONSTRUCTION of the DRAINS.

MATERIALS.	Unit.	Francs.
Sandstone, rough rubble	cube mètre	10·00
,, ,, hammer-dressed	,,	16·00
River sand in natural state	,,	4·50
,, ,, sifted	,,	5·50
Broken pebbles, for béton	,,	6·00
Hydraulic lime (quick), in lump	,,	45·00
,, ,, in hydrate paste	,,	35·00
Echoisy lime, in powder	,,	31·00
Auvergne, or artificial pozzolana	,,	35·00
Plaster of Paris	,,	18·00
Clay for puddling	,,	7·00
Roman cement	220 lbs.	7·50
Portland cement (English)	220 lbs.	13·00
,, ,, (French)	220 lbs.	9·00
Normandy granite, squared	cube mètre	130·00
Mortar of 1 part hydraulic cement, and 3 parts of sand	,,	37·00
Mortar of Portland cement from Boulogne, 1 part, and 4 parts of sand	,,	41·50
Mortar of equal parts of cement and fine sand	,,	62·50
Clay puddling in place	,,	10·00
Béton of 0·78 mètre of pebbles to 0·52 mètre of mortar (composed of 2 parts hydraulic lime in paste, and 5 parts of sand)	,,	17·00
Rough masonry in sandstone; mortar of 2 parts of lime and 5 parts of sand	,,	24·00
Rubble masonry, in mortar of 1 part of cement and 2 parts of sand	,,	36·50
Ashlar masonry in hard stone (lime), in mortar of 1 part of cement and 3 parts of sand	,,	93·00
Brickwork in mortar of 2 parts of lime and 5 parts of sand	,,	61·00
Granite curb-stones 1 foot square	mètre run	17·20
An oak framing for cast-iron cover of shafts, of the largest size	each	30·00
Pair of drain boots for workmen	,,	36·00

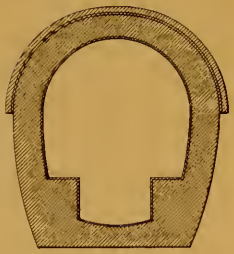
All new works, and the manufacture of barges and cleaning tools are executed under contract.

N° 3.

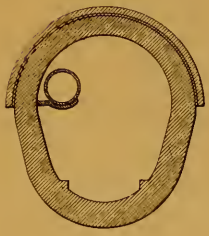
N° 5.



N° 6.

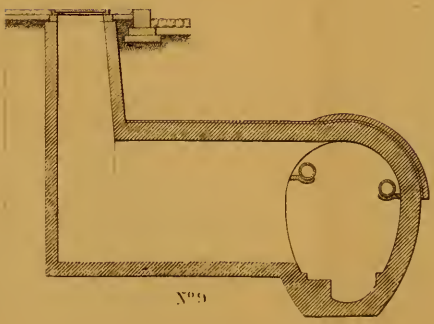


N° 6ª

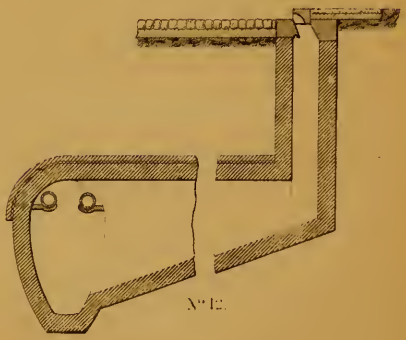


N° 8

N° 10



N° 9



N° 12.

Scale
0 1 2 3 4 5 6 7 8 9 10 feet

KELL BROTHERS LITH. 8 CASTLE ST. HOLBORN

APPENDIX IV.

EPITOME OF COMPARISON BETWEEN THE SYSTEMS OF DRAINAGE OF LONDON AND OF PARIS.

IN PARIS.	IN LONDON.
Drains accommodate as sewage, only rainfall and household water, except the contents of a comparatively small number of public urinals.	They accommodate rainfall, and sewage of all kinds.
Nightsoil is received into cesspools and deodorised for manure.	Nightsoil is carried off by the sewers, and spread over a track of land to be reclaimed and fertilized.
The River Seine is not tidal, and prevents the return to the town of any objectionable matter thrown into it below the town.	The Thames is tidal, and any sewage poured into it in the town must be offensive.
The principal, or northern outfall is 1½ mile from the town.	The principal, or northern outfall is about 14 miles from the town.
In addition to sewage, the sewers receive water-mains, and service-pipes.	The sewers are confined exclusively to the service of sewage.
In the large sewers, especially after providing for the reception of the water-mains, an enormous amount of sectional area, and consequently labour and material, are sacrificed in the adoption of foot-paths.	Great economy of labour and material exists in having drains as small as possible, consistent with efficiency.
The drainage is effected entirely by gravitation.	The drainage is effected by gravitation and pumping.
There is no tide to contend against.	There is tide to contend against.
With inclinations as favourable as I in 1,000 as the minimum, the drains are not self-cleansing.	With an inclination of 1 in 3,520, as a minimum, drains are self-cleansing. Here there is an anomaly, otherwise the superiority must rest with the fact that the sections of the London drains give a greater mean depth.
A length of 217 miles of all kinds of sewers costs about £30,000 annually in their maintenance.	A much greater length is probably cleansed at a less cost in proportion.
A width of 72 feet makes it necessary to place one sewer under each side of the street.	One sewer serves for any width of road.

March 14, 1865.

JOHN ROBINSON M'CLEAN, President,
in the Chair.

No. 1,125.—"On the Main Drainage of London, and the Interception of the Sewage from the River Thames."[1] By Joseph William Bazalgette, M. Inst. C.E.

The majority of the inhabitants of cities and towns are frequently unconscious of the magnitude, intricacy, and extent of the underground works, which have been designed and constructed at great cost, and are necessary for the maintenance of their health and comfort. It is, however, impossible for large numbers of the human species to congregate and live upon a limited space, without provision being made for the rapid removal of the refuse thereby produced. This necessity is perhaps most forcibly illustrated, by the fearful destruction of life from malaria, produced amongst troops suddenly encamped upon ground not previously so prepared for human habitation. The ravages of disease, thus engendered, became a subject of serious alarm amongst the allied troops in the Crimea; and there are many instances of the mortality in armies arising from this cause, having far exceeded the deaths from actual warfare.

Various methods have been, and still are, adopted in different parts of the globe, for obviating the dangers which thus force themselves upon the attention of mankind. The Jews, it is known, kept a furnace called "Gehenna," or "Hell-fire," constantly burning in the Valley of Hinnom, into which the refuse of the city of Jerusalem was daily cast, as well as the dead bodies of criminals; and even the most savage nations are unable entirely to neglect these considerations. The Chinese, sacrificing to a large extent the delicacy and comfort so highly prized by more civilized nations, but with a sound appreciation of the value of town refuse, apply it in the most direct and rude manner to the reproduction of their growing crops. The solid refuse of Paris has also, for many years, been separated and removed for agricultural manure; but the drainage of that city, and of most of the continental towns, has, until of late years, to a large extent flowed over the surface of

[1] The discussion upon this and the preceding Paper occupied portions of four evenings, but an abstract of the whole is given consecutively.

the streets. The drainage of English towns has in this respect been mostly in advance of those of other countries; and London, even prior to the introduction of the improved system, was probably the best-drained city of the present age. One important feature, which it is not the object of this communication to dwell upon, has however, up to the present time, been altogether neglected—the Utilisation of Sewage for agricultural purposes. This subject is now occupying much of the consideration of scientific men, and of the public generally, and is deserving of special consideration in a separate Paper.

Before proceeding to describe the modern works for the improved drainage of London, a glance at the early history of its sewerage may not be uninteresting. The Minutes of Proceedings of some of the earlier Commissions of Sewers contain many curious entries, showing that the subject of sewerage received the attention of the Legislature from a very early date. Amongst others, a proposal by Sir Christopher Wren for improved drainage, nearly two hundred years ago, is preserved in MS. in the records of the ancient Westminster Commission.

"Saturday, y^e^ 13th April, 1678.

"Proposalls delivered by S^re^ Christopher Wren touching the new street in St. Margaret's, viz.—

"It is proposed, That whereas y^e^ new sewer in Westminster, now proposed to be carryed through George yard to Stories corner, and thence through Long ditch to Sre Rob Pyes sluice, by an uniforme riseing frome y^e^ Thames to the sayd sluice, so as to receive a flush of water from the Mill ditch, by meanes of the sayd sluice, for the scouring and cleansing of the sayd sewer. Now, if the sayd sewer which is already brought to Stories corner by a riseing levell, should be carried with a fall y^e^ otherway through Long ditch, and so through Deane's yard, and all along by the Mill ditch, and then be vented into y^e^ Thames, neare y^e^ sluice of the Mill. And if a small branch with a sluice should be brought from the King's canall with His Majesty's allowances. It is conceived this way would be far more advantageous to cleane y^e^ sewer, than y^e^ antient ways of receiving a flush from the Mill pools, and may be done at any ebbe, and the charge will be lesse than y^e^ scouring and wharfeing the Mill poole, because ten times the quantity of water may be afforded from the canall without drawing downe canall above 4 inches, which will be immediately supplyed again at flood, and y^e^ water taking the sewer in the middle and driveing downe two waies to each end of the sewer will more effectually cleanse it.

"That a Draught of a Decree be made according to y^e^ proposalls aforesayd."

"Saturday y^e^ 30th of Nov., 1678.

"Upon readeing a paper intituled, An Estimate of y^e^ Charge of several Works to be done in relation to y^e^ Back Waters in St. Margarett's, Westminster. It is ordered, That the worke therein mentioned, to be done in Brasbyes alley in Gardener's lane, be forthwith done and performed. And that the other particulars in the sayd paper mentioned, be referred to Sir Christopher Wren, who is desired to consider the same and make report what is fitt to be done therein."

Commissioners of Sewers were in those days persons of considerable importance, for on the 4th February, 1663, it was ordered "that y^e^ kinges Majestie (Charles II.) beare one halfe of y^e^ charge of y^e^ carrying away of y^e^ rubbish at the sluice by his said Majesties bouling green," and on the 17th April, 1669, "That Francis Crassett, clerk to this Commission, doo attend his Majesties officers concerning the Kinges arreares which are in arreare upon his said Majestie for casting y^e^ comon sewers synce y^e^ thyme of his Majesties happy restauration," and again in 1768, His Majesty George III. was permitted by an order of Court of the Westminster Commissioners of Sewers, at his own cost, to alter the line of the King's Scholars' Pond Sewer from under Her Majesty the Queen's palace in St. James's Park, and it was—

"Ordered that His Majesty may remove the sewer from under Her Majesty's the Queen's Palace in St. James's Park, by making a new sewer from the north side of this said Palace to the road leading from Buckingham Gate towards Pimlico, at His Majesty's expense if His Majesty so pleases."

Up to about the year 1815, it was penal to discharge sewage, or other offensive matters, into the sewers; cesspools were regarded as the proper receptacles for house drainage, and sewers as the legitimate channels for carrying off the surface waters only. Afterwards it became permissive, and in the year 1847 the first Act was obtained making it compulsory, to drain houses into sewers.

The Fleet Sewer, formerly known as the River of Wells, or the Old Bourne (now called Holborn), was fed by several springs, from which originated the names of many of the populous districts of London, such as Sadler's Well, Bagnigge Well, Lamb's Conduit, Chad's Well, and Clerk's Well or Clerkenwell, which latter derived its name from the parish clerks of the City of London, who used to meet there annually to represent certain parts of Scripture in a theatrical manner, and thither the nobility, the lord mayor and citizens repaired to see the performances.

In 1218, the Fleet supplied the people residing west of Chancery Lane, then called "Foreigners," with water; and in 1307, a mill, the property of the Templars, was removed on the ground that it disturbed the water. The Fleet Sewer was at that time navigated up to Holborn Bridge, and it was not until 1732 that it was, by Act of Parliament, covered in between Holborn Bridge and Fleet Bridge.

The waters from a spring at Tye Bourne and from the Bayswater Brook (now called the Ranelagh Sewer) were also conveyed, in 6-inch leaden pipes, into the neighbouring dwellings; and, in 1730, Queen Caroline fed the Serpentine in Hyde Park with water from

the Ranelagh. Of late years, however, the water so polluted the lake that it has been diverted by a new sewer through the Park.

The Ranelagh and the King's Scholars' Pond Sewers, the Fleet Ditch, and other main valley lines were at this time, and for many subsequent years, open brooks, ponded up at various points along their route, so as to form ornamental waters in the pleasure-grounds of the gentry, who lived in what still continued to be the suburbs of the metropolis. Plate 15 Fig. 2, represents the condition and appearance of the Ranelagh sewer, as taken from actual surveys in 1809. The Commissioners of Sewers of those days were wont to make an annual personal inspection of the sewers under their charge, a duty which has of late years been discontinued.

As the population of London increased, the subsoil became thickly studded with cesspools, improved household appliances were introduced, overflow drains from the cesspools to the sewers were constructed, thus the sewers became polluted, and covered brick channels were necessarily substituted for existing open streams.

Prior to the year 1847, the sewers were under the management of eight distinct Commissions, viz., the City, Westminster, Holborn and Finsbury, Tower Hamlets, Poplar and Blackwall, Surrey and Kent, Greenwich, and St. Katherine's Commissions of Sewers. These were independent bodies; each appointed its own officers, and carried out its drainage works, frequently regardless of the effect thereby produced upon the neighbouring districts, through which the sewage flowed. The works were not constructed upon a uniform system; and the sizes, shapes, and levels of the sewers at the boundaries of the different districts were often very variable. Larger sewers were made to discharge into smaller ones; sewers with upright sides and circular crowns and inverts were connected with egg-shaped sewers; and egg-shaped sewers with the narrow part uppermost were connected with similar sewers having the smaller part downwards.

In the year 1847, these eight Commissions of Sewers were superseded by one Commission, termed "The Metropolitan Commission of Sewers," whose members were nominated by the Government. That Commission entertained opposite views respecting the use of sewers to those which had been previously held, and directed its energies mainly to the introduction of pipe-sewers of small dimensions, in lieu of the large brick sewers previously in vogue, to the abolition of cesspools, and to the diversion of all house drainage (by direct communications) into the sewers, making the adoption of the new system of drainage compulsory; so that, within a period of about six years, thirty thousand cesspools were abolished, and all house and street refuse was turned into the river.

Similar systems were, about the same period, to a large extent adopted in the provincial towns, by which means their drainage has been vastly improved, but the rivers and streams of the country have become very generally and seriously polluted.

During the existence of this Commission, the Author first became officially connected with the drainage of London; but, within nine years after its formation, the Metropolitan Commission of Sewers was six times superseded, and six new and differently constituted Commissions were successively appointed. These were however unable, during their limited period of office, to mature and carry out works of any magnitude.

The second of these Commissions was issued in 1849. The Thames at that time was becoming full of sewage; and as several of the Water Companies then obtained their supply from the river at or near London, the public press began to agitate for a remedy for this rapidly increasing evil. The Commissioners, by advertisement, invited designs for the purification of the river, in answer to which they received one hundred and sixteen different schemes, proposing various methods for the accomplishment of that object, and in the midst of the perplexity of selecting from these designs, and of the public excitement thereby produced, the Commission resigned. The late Mr. Robert Stephenson, Mr. Rendel, and Sir William Cubitt were appointed members of the third Commission, and they undertook the classification and investigation of the merits of these competing plans, and eventually, after much careful consideration, arrived at the conclusion, that whilst the plan of Mr. M'Clean (President Inst. C.E.) was the best, none could be recommended for execution as a whole.

In 1850, Mr. Frank Forster was appointed Chief Engineer of the Commission; under his direction, Messrs. Grant and Cresy commenced the preparation of a plan for the intereeption of the sewage of the area south of the Thames, and Mr. Haywood, the Engineer of the City Commissioners of Sewers, assisted Mr. Forster in the preparation of a similar plan for the districts on the North side.

In 1851, the fourth Commission was appointed, when one of its members prepared and advocated a plan of his own, in opposition to the plan of Mr. Forster. Mr. Forster's health giving way under the excitement of protracted opposition, he resigned his position, and shortly afterwards died.

In 1852, the fifth Commission was issued, and the Author succeeded Mr. Forster as Chief Engineer. Fresh plans for intercepting the sewage of the metropolis still continued to be laid before the Commission, and were from time to time examined and reported on, without any practical result. In 1854, the Author was directed to prepare a scheme of intercepting sewers,

intended to effect the improved Main Drainage of London, and Mr. Haywood was associated with him for the northern portion. The late Mr. Robert Stephenson and Sir William Cubitt afterwards devoted much time and attention to the consideration of the plan so prepared, and eventually recommended its adoption.

In February, 1854, Mr. Cubitt reported that—

"After a very careful examination of the reports and plans, and the elaborate set of sections and details which they (Messrs. Bazalgette and Haywood) have produced, together with the estimate founded thereon, that the whole are worthy of every attention as regards the capacities and inclinations of the various intercepting drains, in relation to the quantities of water they have to carry and discharge. The matter is, in fact, so clearly and minutely set forth in report, plans, and sections, that the Engineers have laid themselves entirely open to detection by any persons who understand practical engineering, inasmuch as, in their present state, the documents would enable such a person to make a correct estimate of the amount at which any portion of the works might be contracted for; a fact highly creditable to the Engineers."

The sixth Commission, formed in 1855, continued to discuss the subject, without coming to any practical result, up to the time of its dissolution, and of the formation of the present 'Metropolitan Board of Works,' in 1856.

But it was not alone the anomalies of the old Commissions, and the necessity for providing for the great increase in drainage matter caused by modern improvements, which compelled the adoption of a general system of Main Drainage. The metropolis had suffered severely in the cholera visitation of 1831-2, again in 1848-9, and lastly in 1853-4. In 1849 the deaths were 18,036, and in 1854 nearly 20,000; and although great differences of opinion existed, and continue to exist, as to the causes of the disease, yet an inspection of the houses in which deaths occurred was sufficient to show that, however occult might be the connection between death and defective drainage, the places formerly most favourable to the spread of disease became quite free from it, when afterwards properly drained.

Acting on the indications afforded by the Registrar-General's return, the Commissioners of Sewers endeavoured to afford an outlet into a good sewer for every suspected locality; but they speedily found that a limit had been put to their operations, by the carelessness and cupidity of preceding generations. Builders had in many cases, especially on the south side of the Thames, availed themselves of the comparative cheapness of the land, and placed their houses in spots not only sewerless, but where no outlets for sewers existed. In designing a system of Main Drainage, these points had to be kept in view,—to provide ample means for the discharge of the large and increasing water supply consequent on the universal adoption of closets, and of the ordinary rainfall and surface

drainage at all times, except during extraordinary storms, and to afford to the low-lying districts a sufficiently deep outfall to allow of every house being effectually relieved of its fluid refuse.

For centuries there had existed Sewers Commissions appointed by the Government, and irresponsible to the ratepayers, upon whom they levied rates, and for whose benefit they expended them, and the substitution of the Metropolitan Board of Works was the first introduction of the system of local self-government. Under this Act London is divided into thirty-nine districts. The City of London and the larger parishes, such as Marylebone and Lambeth, each form one district, and minor parishes are united to form other districts. The ratepayers of each parish, or district, elect from among themselves a prescribed number of representatives, to form a board, who manage the local drainage, paving, lighting, and other improvements, and these district boards select from their body one or more members (proportionate to the population and extent of the district) to form the Metropolitan Board, which consists of forty-five members, presided over by a Chairman, and has control over the Main Sewers, the Thames Embankment, all new streets, and metropolitan improvements, and makes bye-laws for the direction and control of the different vestries and district boards.

The Author, having been appointed Engineer to the Metropolitan Board, was again instructed to prepare a plan for the drainage of the metropolis, and, when completed, it was approved and adopted by the Board. Her Majesty's First Commissioner of Works, however, having a veto under the Act constituting the Board, refused, upon a technical point, to sanction this plan. His decision was resisted by the Board, and the difficulty was ultimately removed. He had, however, referred the plan for examination to a Commission of Engineers named by him, which Commission substituted and recommended a design of their own, in lieu of that approved by the Board. The Royal Commissioners' plan was, in its turn, submitted by the Metropolitan Board of Works to Mr. Bidder, Mr. Hawksley, and the Author, upon whose Report the Board's plan was, after much discussion and delay, eventually adopted, and the works were commenced in 1859. It was through the influence of Lord John Manners, who afterwards became the First Commissioner of Works, that the Board was left free to carry out their system of Main Drainage.

The works involved in that design are now practically completed and in operation. They are illustrated more particularly by the contract drawings and specifications herewith presented to the Institution, and a description of the works forms the more immediate subject of this Paper.

The objects sought to be attained in the execution of the Main Drainage works were the interception of the sewage (as far

as practicable by gravitation), together with so much of the rain-fall mixed with it as could be reasonably dealt with, so as to divert it from the river near London; the substitution of a constant, instead of an intermittent flow in the sewers; the abolition of stagnant and tide-locked sewers, with their consequent accumulations of deposit; and the provision of deep and improved outfalls, for the extension of sewerage into districts previously, for want of such outfalls, imperfectly drained.

Having these objects in view, it is easier and more economical to originate a new and complete system of drainage, than to adapt existing and defective sewers to a uniform and more perfect system.

According to the system which it was sought to improve, the London Main Sewers fell into the valley of the Thames, and most of them, passing under the low grounds on the margin of the river before they reached it, discharged their contents into that river at or about the level, and at the time of low water only. As the tide rose it closed the outlets, and ponded back the sewage flowing from the high grounds; this accumulated in the low-lying portions of the sewers, where it remained stagnant in many cases for eighteen out of every twenty-four hours. During that period the heavier ingredients were deposited, and from day to day accumulated in the sewers; besides which, in times of heavy and long-continued rains, and more particularly when these occurred at the time of high water in the river, the closed sewers were unable to store the increased volume of sewage, which then rose through the house drains and flooded the basements of the houses.

The effect upon the Thames, of thus discharging the sewage into it at the time of low water, was most injurious, because not only was it carried by the rising tide up the river, to be brought back to London by the following ebb-tide, there to mix with each day's fresh supply,—the progress of many days' accumulation towards the sea being almost imperceptible,—but the volume of the pure water in the river, being at that time at its minimum, rendered it quite incapable of diluting and disinfecting such vast masses of sewage.

In the system now adopted, it has been sought to remove these evils by the construction of new lines of sewers, laid at right angles to the existing sewers, and a little below their levels, so as to intercept their contents, and convey them to an outfall 14 miles below London Bridge. As large a proportion of the sewage as practicable is by this means carried away by gravitation, and for the remainder a constant discharge is effected by pumping. At the outlets, the sewage is delivered into reservoirs situate on the banks of the Thames, and placed at such a level as will enable

them to discharge into the river at or about the time of high water. By this arrangement, the sewage is not only at once diluted by the large volume of water in the Thames at high water, but is also carried by the ebb tide to a point in the river, 26 miles below London Bridge, and its return by the following flood tide, within the metropolitan area, is effectually prevented.

At the threshold of any inquiry into this subject, the following important points required to be solved:—

1st. At what point and state of the tide can the sewage be discharged into the river so as not to return within the more densely inhabited portions of the metropolis?

2nd. What is the minimum fall which should be given to the intercepting sewers?

3rd. What is the quantity of sewage to be intercepted, and does it pass off in a uniform flow at all hours of the day and night, or in what manner?

4th. Is the rainfall to be mixed with the sewage, in what manner and quantities does it flow into the sewers, and is it also to be carried off in the intercepting sewers, or how is it to be provided for?

5th. Having regard to all these points, how are the sizes of the intercepting and main drainage sewers to be determined?

6th. What descriptions of pumping engines and of pumps are best suited for lifting the sewage of London at the pumping stations?

So comprehensive a subject, involving not only the above, but many other important topics, cannot be fully considered within the limits of an ordinary Paper, in which these questions can only be briefly touched upon.

The position of the outfalls and the time of discharge into the river were arrived at in the mode described in the following extract from the Report of the late Mr. Robert Stephenson and Sir William Cubitt, dated the 11th December, 1854; wherein they give a brief summary of a series of experiments made by the late Mr. Frank Forster, and subsequently repeated by Captain Burstal, R.N., and the Author, upon this subject—

"On the 13th of July, 1851, a float was put into the centre of the river opposite Barking Creek two hours after high water. This time was chosen, because it was found that sewage discharged into the river two hours before high water arrived at about the same point above Barking Creek as sewage discharged two hours after high water did by the next flood tide. At low water the float reached 11¾ miles below that point, and returned with the next flood tide to 1 mile above it, having gone 12¾ miles that flood, it being then the period of spring tides.

"As the neaps came on, the float continued to work lower down at each succeeding high water, and by the 24th of July it was 13 miles

below Barking Creek at high water, having gone down the river 14 miles during the falling off of spring tides to neap tides. As the floods again became stronger, it worked up the river each succeeding tide until the 29th July, when it again came within 5 miles below Barking Creek at high water, having worked up the river 9 miles from high water neap tides to high water spring tides, the excess of the ebbs over the floods being only 5 miles in fourteen days."

"Another experiment was tried at the same place on the 6th of August, 1851, it being then lowest neaps, and the float being put down two hours after high water. It worked up each succeeding high water till top springs on the 12th of August, when it reached 6¼ miles above Barking Creek at high water. The float then again worked down the river, till the 20th of August, 9½ miles below Barking Creek, being a distance of 16 miles during the falling off of spring tides to neap tides. The excess of ebbs over the floods would in this case have been about 7 miles in fourteen days. The wind and other causes would vary the result, but it may be roughly assumed, that a substance in suspension works up the river about 1 mile a day at each high water as the springs strengthen, and down the river 2 miles a day as they fall off."

The main object was of course to determine, how near to London the sewage could be discharged into the river, at or near high water, without finding its way back again to the inhabited parts of the town. The experiments proved, that it was essential to go as far as Barking Creek; and also, as regards the level of the discharge, they demonstrated that it should take place at or as near high water as practicable.

Now, although it is desirable to fix the place of discharge as far below the metropolis as possible, it will be found that a practical limit to this point is imposed on the north side of the river, by the advantages gained from a discharge by gravitation, and by the necessity of maintaining a sufficient fall in the sewers; and on the south side, in order to preserve as a safety outlet a discharge into the river at low water by gravitation, in case of accident to the pumps, as well as during excessive floods.

As regards the time of discharge, it is demonstrated by the same series of experiments that—

"The delivery of the sewage at high water into the river at any point is equivalent to its discharge at low water at a point 12 miles lower down the river, therefore the construction of 12 miles of sewer is saved by discharging the sewage at high instead of low water."

As to the velocity of flow and the minimum fall, though it is necessary to economize the fall of the sewers in order to save pumping, yet a sufficient velocity of flow to prevent deposit must at the same time be maintained, and the question—What is a sufficient flow? must be determined.

Upon this point Mr. Wicksteed, in his Report upon the Drainage of Leicester (p. 19), states—

"From experiments made by me with great care, I find that with a

bottom velocity of 16 inches per second only (or 0·90 mile per hour) heavy pieces of brick, stone, &c., will be removed, and that with a velocity of 21¾ inches (or 1·24 mile per hour), even iron borings and heavy slag will be removed. The above minimum velocity will therefore be sufficient."

Mr. Beardmore, in his work on Hydraulics, states (p. 8) that "a velocity of 150 feet per minute (or 1¾ mile per hour) will generally prevent deposits in pipes and sewers."

Mr. John Phillips states (see First Report of Sanitary Commission, 1847, p. 177),—

"From observation and experiment, I find that it requires a constant velocity of current to be running through the sewers equal to about 2½ feet per second, or about 1¾ mile per hour, to prevent the soil from depositing within them."

Professor Robison, in his "Theory of Rivers," states, at page 465, that—

"We learn from observation, that a velocity of 3 inches per second at the bottom will just begin to work up fine clay fit for pottery, and however firm and compact it may be, it will tear up."

"A velocity of 6 inches will lift fine sand, 8 inches will lift sand as coarse as linseed, 12 inches will sweep along fine gravel, 24 inches will roll along rounded pebbles an inch diameter, and it requires 3 feet per second at the bottom to sweep along shivery angular stones of the size of an egg."

It is difficult to lay down any general rule upon this point, because the conditions of sewers, as to the quantity of deposit passing into them, and the ordinary volume of the sewage flowing through them, vary considerably. But the Author does not hesitate to rely upon these opinions, confirmed as they are by his own observations and experience, which lead him to regard a mean velocity of 1½ mile per hour, in a properly protected main sewer, when running half full, as sufficient, more especially when the contents have previously passed through a pumping station.

Having thus determined the minimum velocity, it becomes necessary to ascertain the quantity of sewage to be carried off, before the fall requisite to produce that velocity can be estimated. This quantity varies but little from the water supply with which a given population is provided; for that portion which is absorbed and evaporated is compensated for by the dry weather underground leakage into the sewers. The water supply to various parts of London in 1856 varied from 20 gallons to 25 gallons per head per diem; but a more liberal supply was contemplated, and that supply was likely to be further augmented, by an increase in the population in certain districts not then wholly built upon. It was ascertained that a district of average density of population, when wholly built upon,

contained 30,000 people to the square mile, so that in districts containing that, or more than that number of people to the square mile, the actual numbers were ascertained and provided for; but in districts where the population was below that number, provision has been made for an increase of population up to 30,000 people to the square mile, except over the outlying districts, where provision has been made for a population of only 20,000 to the square mile.

An improved water supply, equal to 5 cubic feet, or $31\frac{1}{4}$ gallons, per head for such contemplated increased population, has moreover been anticipated. The effect upon the Thames of the diversion from its channel of water for the supply, not only of London but also of other towns, appears already to have attracted the notice of the Legislature.

Experience has shown, that sewage is not discharged into the sewers at a uniform rate throughout the twenty-four hours, nor even throughout the day. Mr. Lovick, the Assistant Engineer, made some careful observations on this subject for the late Metropolitan Commission of Sewers. The habits of the population in various parts of London are indicated by the flow of sewage through the sewers; the maximum flow in the more fashionable districts of the West end being two or three hours later than from the East end. Taking, as before, a liberal margin beyond the results of actual measurements, provision has been made for one-half of the sewage to flow off within six hours of the day; and thus the maximum quantity of sewage, likely hereafter to enter the sewers at various parts of the metropolis, has been arrived at.

How to dispose of the rainfall is a question of considerable difficulty, and has given rise to much diversity of opinion. This arises from the fact that, whilst it is in itself harmless, and even advantageous, to the river, it sometimes falls suddenly in large quantities. These considerations have induced theorists to advocate, that the rainfall should not be allowed to flow off with the sewage, but should be dealt with by a separate system of sewers. This theory is, however, most impracticable. It would involve a double set of drains to every house, and the construction and maintenance of a second series of sewers to every street. Applied to London, it would involve the re-draining of every house and every street in the metropolis; and, according to a moderate estimate, it would lead to an expenditure of from ten to twelve millions of money, while the interference with private property would alone render such a proposition intolerable.

Careful observations of the quantity of rain falling on the metropolis within short periods have been made by the Author for many years. Taking an average of several years, it has been

ascertained that there are about one hundred and fifty-five days per annum upon which rain falls; of these there are only about twenty-five upon which the quantity amounts to $\frac{1}{4}$ of an inch in depth in twenty-four hours, or the 1-100th part of an inch per hour, if spread over an entire day. Of such rainfalls a large proportion is evaporated or absorbed, and either does not pass through the sewers, or does not reach them until long after the rain has ceased. In the Report of Mr. Bidder, Mr. Hawksley, and the Author, in 1858, on this subject, it is stated that continuous observations, and as far as practicable protected from disturbing influences, had been taken at the close of the previous year, and that these observations, which were recorded in the Appendix to the above Report, had enabled them to arrive at some reliable conclusions, and that,—

"The result of these observations distinctly establishes the fact, that the quantity of rain which flowed off by the sewers was, in all cases, much less than the quantity which fell on the ground; and although the variations of atmospheric phenomena are far too great to allow any philosophical proportions to be established between the rainfall and the sewer flow, yet we feel warranted in concluding, as a rule of averages, that $\frac{1}{4}$ of an inch of rainfall will not contribute more than $\frac{1}{4}$ of an inch to the sewers, nor a fall of $\frac{4}{10}$ of an inch more than $\frac{1}{4}$ of an inch. Indeed, we have recently observed rainfalls of very sensible amounts failing to contribute any distinguishable quantity to the sewers."

But there are, in almost every year, exceptional cases of heavy and violent rain-storms, and these have measured 1 inch, and sometimes even 2 inches, in an hour. A quantity equal to the 1-100th part of an inch of rain in an hour, or $\frac{1}{4}$ of an inch in twenty-four hours, running into the sewers, would occupy as much space as the maximum prospective flow of sewage provided for; so that, if that quantity of rain were included in the intercepting sewers, they would, during the six hours of maximum flow, be filled with an equal volume of sewage, and during the remaining eighteen hours additional space would be reserved for a larger quantity of rain. Taking this circumstance into consideration, and allowing for the abstraction due to evaporation and absorption, it is probable that if the sewers were made capable of carrying off a volume equal to a rainfall of $\frac{1}{4}$ of an inch per day, during the six hours of the maximum flow, there would not be more than twelve days in a year on which the sewers would be overcharged, and then only for short periods during such days. But exceptional rain-storms must be provided for, however rare their occurrence, or they would deluge the property on which they fell. As it would not have been wise, or practicable, to have increased the sizes of the intercepting sewers much beyond their present dimensions, in order to carry off rare and excessive thunderstorms, overflow weirs, to act as safety-valves in times of storm, have been

constructed at the junctions of the intercepting sewers with the main valley lines: on such occasions the surplus waters will be largely diluted, and, after the intercepting sewers are filled, will flow over the weirs, and through their original channels into the Thames.

Having thus determined the quantities of sewage and rainfall to be carried off, and the rate of declivity of the sewer required for the necessary velocity of flow, the sizes of the intercepting sewers were readily determined by the formulæ of Prony, Eytelwein, and Du Buat; and the sizes of the drainage sewers by the useful formula of Mr. Hawksley, which, with some modifications, may be applied to a variety of conditions and circumstances, and with respect to which the Author would again quote from the Report of the late Mr. R. Stephenson and Sir William Cubitt of the 11th December, 1854, in which it is said:—

"No part of Engineering science has been more industriously investigated than the laws that govern the flow of water in pipes and open channels; and it is probably not too much to say, that the formulæ which represent these laws rank amongst the most truthful that the professional man possesses. They have been the subject of laborious experimental investigation of the most elaborate character, and their results have been tested by the practical man under every variety of conditions, without their truth being impugned in the slightest degree. The principles upon which they are founded have been sanctioned and adopted by Prony, Eytelwein, Du Buat, and others; and it is to them that we are indebted, in a great measure, for the simple practical form which they present. Our own Engineers have modified them to suit particular circumstances, and given them more extensive usefulness. Mr. Hawksley, amongst others, has especially contributed to render the principles which they embrace applicable to almost every variety of condition which the complete drainage of large towns involves; and we shall have occasion, almost immediately, to adduce some instances within the metropolis, where the facts confirm theoretical deductions in a very remarkable manner, and lead irresistibly to the conclusion that they may be implicitly depended on."

With respect to the description of pumping engines and pumps to be employed, various opinions existed as to the comparative advantages of Cornish or rotative engines, and as to the respective merits of centrifugal and screw pumps, chain pumps, lifting bucket wheels, flash wheels, and of every variety of suction or plunger pump and pump valve for raising the metropolitan sewage. In 1859, numerous competing designs, involving all these principles, were reported upon by Messrs. Stephenson, Field, Penn, Hawksley, Bidder, and the Author; and the pumping engines and pumps subsequently designed for, and adopted by, the Metropolitan Board of Works are based upon the recommendations contained in that Report. The engines are condensing double-acting rotative beam engines, and the pumps are plunger or ram pumps, the sewage

being discharged from the pumps through a series of hanging valves.

The contractors for the engines at Crossness and at Abbey Mills guarantee that the engines shall, when working, raise 80 million lbs. one foot high, with one cwt. of Welsh coal.

A primary object sought to be attained in this scheme was the removal of as much of the sewage as practicable by gravitation, so as to reduce the amount of pumping to a minimum. To effect this, three lines of sewers have been constructed on each side of the river, termed respectively the High Level, the Middle Level, and the Low Level. The High and the Middle Level Sewers discharge by gravitation, and the Low Level Sewers discharge only by the aid of pumping. The three lines of sewers north of the Thames converge and unite at Abbey Mills, east of London, where the contents of the Low Level will be pumped into the Upper Level Sewer, and their aggregate stream will flow through the Northern Outfall Sewer, which is carried on a concrete embankment across the marshes to Barking Creek, and there discharges into the river by gravitation.

On the South side, the three intercepting lines unite at Deptford Creek, and the contents of the Low Level Sewer are there pumped to the Upper Level, and the united streams of all three flow in one channel through Woolwich to Crossness Point in Erith Marshes. Here the full volume of sewage can flow into the Thames at low water, but will ordinarily be raised by pumping into the reservoir.

With respect to the form of the sewers, as the intercepting sewers carry off only the 1-100th part of an inch of rain in an hour, and the volume of sewage passing through them is at all times considerable, the flow through these sewers is more uniform than in drainage sewers constructed to carry off heavy rain-storms. The form, therefore, generally adopted for the intercepting sewers is circular, as combining the greatest strength and capacity with the smallest amount of brickwork and the least cost. In the minor branches, for district drainage, the egg shape, with the narrow part downwards, is preferable; because the dry weather flow of the sewage being small, the greatest hydraulic mean depth, and consequently the greatest velocity of flow and scouring power, is obtained by that section in the bottom at the period when it is most required, and the broader section at the upper part affords room for the passage of the storm-waters, as also for the workmen engaged in repairing and cleansing.

Having thus briefly glanced at the early history of the drainage of London, and the circumstances which led to the adoption of the

main intercepting scheme, and a few of the considerations and general principles upon which that scheme is based, a more detailed description of the works will now be given, as well as of some of the peculiarities or difficulties met with during their construction.

The North Side of the Thames.

The High Level Sewer was constructed under one contract. It commences by a junction with the Fleet Sewer, at the foot of Hampstead Hill, and passes along Gordon House-lane, and across the Highgate-road. It is carried through Tufnell-park-road, Holloway-road, under the Great Northern Railway, and the New River to High-street, Stoke Newington, at Abney Park Cemetery. It then passes under the Rectory and Amhurst roads to Church-street, Hackney; under the North London Railway, through Victoria-park, and under Sir George Duckett's Canal to a junction with the Middle Level Sewer. (Plate 16.) Up to this point it is a drainage sewer, that is to say, it is a substitute for the open Fleet and Hackney Brook main sewers, which have since been filled in and abandoned; and it has been constructed of such dimensions, as to be capable of carrying off the largest and most sudden falls of rain. It is about 7 miles long, drains an area of about 10 square miles, and intercepts the sewage of Hampstead, part of Kentish Town, Highgate, Hackney, Clapton, Stoke Newington, and Holloway. A portion of the district adjoining the Hackney Marshes is so low, that it was necessary to drain it through a branch passing into the Low Level Sewer. The form of the High Level Sewer is mostly circular, and it varies in size from 4 feet in diameter to 9 feet 6 inches by 12 feet; its fall is rapid, ranging at the upper end from 1 in 71 to 1 in 376, and from 4 feet to 5 feet per mile at the lower end.

It is constructed of stock brickwork, varying in thickness from 9 inches to 2 feet 3 inches, and the invert is lined with Staffordshire blue bricks, in order to withstand the scour arising from the rapid fall. One tunnel, from Maiden-lane towards Hampstead, is about ½ a mile long, and great care was necessary in tunnelling under the New River, its channel being on an embankment where it intersects the line of sewer; also under the Great Northern Railway, at a place where its embankment is 30 feet high, the sewer being 7 feet 6 inches in diameter, and the brickwork 14 inches in thickness.

Much house-property was successfully tunneled under at Hackney. One house, adjoining the railway station, was underpinned and placed upon iron girders, and the sewer, being there 9 feet 3 inches in diameter, was carried through the cellar without

further injury to the house. The sewer is carried close under the bottom of Sir George Duckett's Canal, the distance between the soffit of the arch of the sewer and the water in the canal being only 24 inches. The bottom of the canal and the top of the sewer are here formed of iron girders and plates, with a thin coating of puddle, and no leakage from the canal has taken place. This was the first portion of the Main Drainage works executed, and it was completed in the year 1854. The whole of the High Level Sewer, including the Penstock Chamber, was completed in May, 1861, and has been in full operation since that date.

The Penstock Chamber, which is formed at the junction of the High and the Middle Level Sewers at Old Ford, Bow, is provided with five large iron penstocks worked by machinery, by which the sewage can be diverted at will either into the two lower channels formed for the discharge of the storm-waters into the River Lea, or into the two upper channels constructed over that river, and forming the commencement of the Northern Outfall Sewer. As a rule the lower channels will be closed, and the sewage will flow through the two upper channels to Barking Creek; but in times of heavy rain, as soon as the waters have risen to the top of the upper channels, the surplus will flow over five weirs, constructed in the chamber, into the lower channels, and be discharged by them into the Lea. In case of any sudden accident to the intercepting sewers, the whole of the sewage could, by raising the lower penstock, be diverted in a few minutes into the Lea.

The penstock and weir chamber is a novel arrangement, which has proved to be simple and satisfactory in its operation, and it places three-fourths of the Northern sewage completely under command. It is built in brickwork, is about 150 feet in length, 40 feet in breadth, and, in places, 30 feet in height.

The principal difficulties to be overcome during the construction of this line of sewer arose from the continued combinations and strikes, which at that time prevailed amongst the workmen, in various parts of England. It is to be hoped that the good sense and good feeling of both the parties concerned will find means for avoiding a recurrence of these public calamities. It is curious to notice, that the injury thus produced was considered so serious in the reign of Edward VI. as to induce the Legislature to pass a statute for the repression of strikes and combinations amongst the workmen. The statute provided that, upon conviction, the offenders should be punished by means not quite consistent with the policy of the present age, viz.—by the infliction not only of fine or imprisonment, but also, for repeated offences, by the punishment of the pillory, having an ear cut off, and being rendered infamous and incapable of giving evidence upon oath.

A long-continued wet season prevented the manufacture of bricks, while the demand for them was greatly increased by the formation of several metropolitan railways and other public works at the same period; the prices of building materials and labour rose therefore considerably, and the combination of these untoward circumstances rendered this an unprofitable work for the contractor.

The Middle Level Sewer was formed under one contract, and is carried as near to the Thames as the contour of the ground will permit, with the object of intercepting as much sewage as possible by gravitation, and of reducing to a minimum the low level area which is dependent upon pumping. The area intercepted by this sewer is 17½ square miles in extent, and is densely inhabited. The sewer commences near the Harrow Road at Kensal Green, passes under the Paddington Canal into the Uxbridge Road at Notting Hill, along Oxford Street, Hart Street, Liquorpond Street, and across Clerkenwell Green; thence by way of Old Street Road to High Street, Shoreditch, along Church Street, Bethnal Green Road, and Green Street, under the Regent's Canal and the North London Railway, to a junction with the High Level Sewer at the Penstock Chamber at Bow. (Plate 16.) In order to enlarge the area drained by gravitation, a branch, 4 feet by 2 feet 8 inches, with a fall of 4 feet per mile, is carried along Piccadilly, passes through Leicester Square and Lincoln's Inn Fields to the main line at King's Road, Gray's Inn Road. The length of the main line is about 9½ miles, and of the Piccadilly Branch 2 miles, besides which there are minor branches and feeders. The fall of the Main Sewer varies from 17½ feet per mile at the upper end, by a gradual reduction, to 2 feet per mile at the lower end.

The sizes vary from 4 feet 6 inches by 3 feet, to 10 feet 6 inches in diameter, and lastly to 9 feet 6 inches by 12 feet at the outlet. About 4 miles of the main line, and the whole of the Piccadilly Branch, were constructed by tunneling under the streets, at depths varying from 20 feet to 60 feet. This sewer is formed mostly in the London clay; to the east of Shoreditch it is constructed through gravel, and during the execution of the works under the Regent's Canal, the water burst into the sewer, fortunately giving sufficient warning to prevent any loss of life. The sewer was afterwards constructed under the canal, first by enclosing one-half of the width of the tunnel at a time within a coffer-dam, and then by open cutting.

The Middle Level Sewer is carried over the Metropolitan Railway by a wrought-iron aqueduct of 150 feet span, weighing 240 tons; the depth of construction between the under side of the aqueduct and the inverts of the double line of sewers being only 2½ inches. As the traffic of the railway could not be stopped during the

construction of the aqueduct, which is only a few inches above the engine chimneys, the structure was built upon a stage, at a height of 5 feet above its intended ultimate level, and was afterwards lowered into place by means of hydraulic rams. This stage was necessarily of great strength and was carefully constructed; the sewers being formed by wrought-iron plates riveted together.

The Middle Level Sewer is provided with weirs, or storm-overflows, at its various junctions with all the main valley lines. It has recently been completed, and is now in active operation.

The Low Level Sewer, besides intercepting the sewage from the low level area, which contains 11 square miles, is also the main outlet for a district of about 14½ square miles, forming the western suburb of London, which is so low, that its sewage has to be lifted at Chelsea a height of 17½ feet, into the upper end of the Low Level Sewer. This sewer commences at the Grosvenor Canal, Pimlico, and passes along Lupus Street and Bessborough Street, to and along the river side from Vauxhall Bridge. From Westminster Bridge to Blackfriars it is being formed as part of the Thames Embankment (Plate 17); and thence it will pass under a portion of the new street to the Mansion House, and will probably take the line of the Inner Circle Railway to Tower Hill. From Tower Hill it is being formed mostly by tunneling along Mint Street, Cable Street, Back Road, Commercial Road, and under the Limehouse Cut and Bow Common. It is now being tunneled under the River Lea, on its route to the Abbey Mills pumping station, where its contents will be raised 36 feet by steam power. It has two branches:—one from Homerton, and the other from the Isle of Dogs. This island was formerly a dismal marsh, and received its name from the circumstance of the king's hounds having been kept there, when the Court was at Greenwich. It is now the site of extensive factories and works, and is largely populated by artisans and workmen. Its drainage can only be perfected by the aid of pumping, the beneficial effect of which was so well described by the late Mr. R. Stephenson and Sir W. Cubitt, when they compared it to the lifting of the whole district out of a hollow, on to high ground above the level of the river. The length of the main line is 8¼ miles, and its branches are about 4 miles in length. Its size varies from 6 feet 9 inches to 10 feet 3 inches in diameter, its inclination ranges from 2 feet to 3 feet per mile, and it is provided with storm-overflows into the river.

The Western Division includes Fulham, Chelsea, Brompton, Kensington, Shepherd's Bush, Hammersmith, and part of Acton. It was originally intended to deodorise, or utilise, the sewage of this district in its own neighbourhood, rather than to incur the

heavy cost of carrying it to Barking, and lifting it twice on its route to that place. But strong objections to this having been raised, the latter and more costly plan has since been adopted, and now forms part of the Low Level system of drainage.

In this district a new system of main sewers has been laid, the sewers being conveyed into one channel passing under the West London Extension Railway, and the Kensington Canal, near to Cremorne Gardens, where a temporary pumping station has been erected, and the sewage is, and will continue to be, lifted into the river, until the Low Level Sewer is completed.

The Chiswick Line commences at Chiswick Mall, and passing near to the river and along the Fulham Road, and Walham Green, again skirts the river to Cremorne Gardens, and will be extended eventually to the permanent pumping station near the Grosvenor Canal.

The Fulham branch commences at Fulham Bridge, and joins the Chiswick line at the King's Road.

The size of the main line varies from 4 feet by 2 feet 8 inches to 4 feet 6 inches in diameter, with a fall of 4 feet per mile, the depth below the surface being from 14 feet to 30 feet. The branch varies in size from 3 feet 9 inches by 2 feet 6 inches to 4 feet 6 inches by 3 feet, its fall being $10\frac{1}{3}$ feet per mile, and its depth about 17 feet.

The Acton branch is carried along the Uxbridge Road from the Stamford Brook, at Wormwood Scrubs, to the Counters Creek Sewer at Royal Crescent, Notting Hill, into which it diverts the water from the higher ground, and which forms a storm-outlet into the Thames, near Cremorne Gardens. The Uxbridge Road Sewer varies from 3 feet 9 inches by 2 feet 6 inches to 4 feet by 2 feet 8 inches ; it has a fall of 4 feet per mile, and is about 14 feet deep.

The Chiswick Sewer is $3\frac{1}{4}$ miles long, the Fulham Sewer 1 mile 720 feet, and the Acton branch $1\frac{1}{2}$ mile. Besides these, there are various other minor branches and works. These for the present discharge into a large well or sump, at the temporary pumping station, near Cremorne Gardens.

The works were executed mainly through gravel, charged with such large volumes of water, that it was necessary to lay stoneware pipes under the inverts of the sewers, to lower the water in the ground, and to convey it to numerous and powerful steam pumps in the line of the works, before the sewers could be constructed. The operation of passing under railways and canals, difficult in so treacherous a subsoil, was successfully accomplished, and no serious accidents or failures occurred.

The Northern Outfall Sewer (Plate 18) is a work of peculiar

construction; as, unlike ordinary sewers, it is raised above the level of the surrounding neighbourhood in an embankment, which has the appearance of a railway embankment, and it is carried by aqueducts over rivers, railways, streets, and roads. Rails upon which the contractors' steam-engines and trucks have been constantly travelling, are at the present time laid along the top of it. It commences by a junction with the High and Middle Level Sewers, at the Penstock Chamber at Bow, and passes immediately under the rails of the North London Railway, which are carried over it on girders. It then passes under Wick Lane, which has been raised 18 feet, and then over the River Lea by a wrought-iron aqueduct of 57 feet span. This aqueduct consists of two wrought-iron culverts of the same section as the brick sewers, and over these is formed a roadway with parapet walls, the whole being supported by three wrought-iron plate girders. Indeed, all the aqueducts on this line of sewer are so constructed as to carry a wide roadway upon plates and girders on the top of them. Four other streams between the River Lea and the Stratford Road are crossed over, by iron tubes, of spans varying from 18 feet to 45 feet; and the sewers pass close under the rails of the Eastern Counties Railway, where it is on an embankment, the work having been executed without any interference with the traffic on the railway. The Outfall Sewer, up to this point, consists of two culverts, each 9 feet by 9 feet, placed side by side, formed with upright sides, semicircular crowns and segmental inverts. These are built upon a solid concrete embankment, carried through the peat soil down to the gravel, which is in many places at a great depth below the surface. Concrete is also carried up with a slope of 1 to 1, so as to form an abutment to the sides of the sewers. The whole structure is then covered with an earthen embankment, with slopes of $1\frac{1}{2}$ to 1, the foot of which is fenced in by a quick-set hedge and a ditch, and presents the appearance of a simple railway embankment. It is executed of sufficient strength to carry a railway or a roadway on the top, and will no doubt, at a future time, be used for some such public purpose. The outer earthen embankment not being carried below the surface, has from time to time subsided into the peat marshes through which it is formed, and these settlements have been made good in the ordinary manner; but the sewer and its concrete embankment have shown no sign of settlement or fracture since their completion. At the Stratford Road, the top of the sewer was depressed and carried under the road by four culverts, each 6 feet high and 7 feet 3 inches wide, covered with cast-iron plates. A large amount of property was purchased, and the road raised 10 feet upon a viaduct to pass over the sewer at an inclination of 1 in 50. From the Stratford Road the double line of sewer is continued over Abbey Mill Lane, by two self-

supporting wrought-iron tubes, to the Abbey Mills pumping station, where the contents of the Low Level Sewer will be raised 36 feet. From this point three parallel lines of sewer, of the same form and dimensions as those before described, are continued to the outlet at Barking Creek. Gates and overflow weirs are formed in the line of these culverts, enabling the sewage to be turned into either or all of them at will, and preventing any one of them being at any time overcharged. Just beyond the pumping station, the three lines pass over the Channelsea River and Abbey Creek, by cast-iron culverts, supported by four wrought-iron plate girders of two spans of 40 feet each. They are then carried over Marsh Lane, the North Woolwich and the Bow and Barking Railways, by aqueducts somewhat similar to those already described. These railways were lowered to enable the sewer to pass over them; for the sewer being reduced to a minimum uniform fall of 2 feet per mile, could not be raised or depressed like a railway, to accommodate its levels to those of previously existing works. This, indeed, constituted one of the great difficulties experienced in laying out the line of the Outfall Sewer, for the district through which it passes was already closely intersected by public works. For the same cause, also, the thickness of the ironwork, between the bottom of the sewer and the under side of the aqueduct, was reduced to a minimum, and it does not in most cases exceed 5 inches.

For a distance of about $1\frac{1}{2}$ mile at the lower end of this sewer, so great was the depth of the peat in the marshes, that it would have been very costly to have excavated the whole of the ground down to the gravel, and to have filled it in with solid concrete. The plan therefore adopted for the foundations of this length, was to excavate cross trenches 6 feet 6 inches wide, at distances of 21 feet from each other, down to the solid ground, and to fill these in with concrete piers, upon which brick arches of four rings in thickness were turned, and the sewers were built upon these arches. The top of the bank is 40 feet wide, and in some cases 25 feet above the level of the marshes.

From the crossing of the Bow and Barking Railway, the triple sewer is constructed in brickwork to its outlet at Barking Creek; crossing in its route the five following roads, viz.—Balaam Street, Plaistow, Barking Road, Prince Regent Lane, Blind Lane, and East Ham Hall Manor Way, which were raised for the purpose 6 feet, 8 feet, 13 feet, 20 feet, and 16 feet, respectively.

The invert of the sewer at the outlet is about 18 inches below high-water mark; but before entering the river, the sewage falls over an apron a depth of 16 feet, and is discharged by nine culverts, each 6 feet high by 6 feet wide, laid at the level of low-water spring-tides. The three upper sewers are, however, fitted

with penstocks, before reaching the tumbling bay, to afford the means of closing the river outlet, and of diverting the sewage into the reservoir, in which it will be stored for about eleven hours per tide. The reservoir is so situate, that the sewers form one side of it, and a communication is made between them by sixteen openings, through which, when the penstocks are closed, the sewage enters the reservoir, and is there stored until high water. The sluices at the lower part of the reservoir are then opened, and allow the sewage in the reservoir to be discharged into the river through the nine 6-feet culverts; and the three penstocks, at the river outlet, being opened at the same time, the sewage is simultaneously discharged directly into the river from the outfall sewers without being first passed through the reservoir. The upper openings from the outfall sewer into the reservoir are also fitted with sluices, to enable the communication between the sewer and the reservoir to be shut off in cases of necessity, and the whole of the waters to be discharged over the tumbling bay. At the river end of the nine culverts, a channel is cut in the bed of the river, the floor of which is formed of concrete, and the sides protected by campsheathing, so that the sewage is discharged into the bed of the river at the time of high water. The whole of this line is practically completed, and has been in operation since March, 1864.

The Barking Reservoir is $16\frac{3}{4}$ feet in average depth, and is divided by partition walls into four compartments, covering altogether an effective area of 412,384 superficial feet, or about $9\frac{1}{2}$ acres. The external and partition walls are of brickwork, and the entire area is covered by brick arches, supported upon brick piers, the floor being paved throughout with York stone. The reservoir, being almost entirely above the general surface of the ground, is covered by an embankment of earth, rising about 2 feet above the crown of the arches. The ground over which it is built being unfit to sustain the structure, the foundations of the piers and of the walls were carried down in concrete to a depth of nearly 20 feet.

The sewage is ordinarily prevented rising above a certain level in the reservoir, by means of a weir or overflow in the partition walls, which are built hollow, the spaces communicating with the discharging culverts below the outfall sewers. In cases of necessity, however, the reservoirs can be filled above the weir level, by closing the penstocks fitted to the discharging culverts at their entrance into the tumbling bay before referred to. A culvert, communicating with the river, is built at the back of the reservoir, having openings into each compartment fitted with penstocks, and by these means any one of the compartments may be filled with tidal water at the

top of the tide, and be flushed out by its discharge at the period of low water. This reservoir is completed, and has been in efficient operation since August, 1864.

The Abbey Mills Pumping Station will be the largest establishment of the kind on the Main Drainage Works, providing, as it does, engine power to the extent of 1,140 H.P., for the purpose of lifting a maximum quantity of sewage and rainfall of 15,000 cubic feet per minute a height of 36 feet.

The engine power is here divided amongst eight engines, each being equivalent to 142 H.P. Each engine is furnished with two boilers, making sixteen boilers in all. The engines are contained in one building, cruciform in plan, and are arranged in pairs, two engines in each arm of the cross. These engines, as in all the other pumping establishments on these works, are expansive, condensing, rotative beam engines, but are somewhat more powerful than those used elsewhere, the cylinders being 4 feet 6 inches in diameter with a length of stroke of 9 feet. The pumps differ also in being double acting, a circumstance which allows of the air-pump, &c., being worked from the main beam, instead of from a distinct beam, as at the other stations. Each engine works two pumps, having a diameter of 3 feet 10½ inches and a length of stroke of 4½ feet. The boilers are each 8 feet in diameter, and 30 feet long, with double furnaces.

The engine-house is divided in height into three compartments, the lower one being the pump-well, into which the sewage is conveyed from the Low Level Sewer, the intermediate one forming a reservoir for condensing water, and the upper being more correctly the engine-house, in which are contained the eight engines. The lower part of this building will be laid about 3 feet above the bottom of a thick stratum of clay, overlying a considerable thickness of sand with water, through which the foundations are to be carried, by piling, on to a bed of firm gravel below. The boiler-houses and other portions of the work will be founded upon the clay stratum overlying the sand. As these deep foundations are situate in close proximity to the Northern Outfall Sewer, which is contained in an embankment above the general level of the ground, great caution will be requisite to prevent any settlement in that sewer. The boiler-house and coal stores are to be built between the outfall sewer and the engine-house, keeping the deep excavations as far distant from the sewer as practicable. The coal stores will be built with their floors level with the stoke-holes in the boiler-house, and tramways will be laid from one to the other; one side of the coal stores forming also the front side of the boiler-house. This floor will be only slightly below the present surface of the ground, which is 6 feet below high water. Tramways will be

laid from the top of the coal stores to the Abbey Mill River, adjacent to the works, where a wharf wall will be built for landing coals and other materials.

The sewage from the Low Level Sewer, before entering the pump wells, will pass through open iron cages, the bars of which will intercept any substances likely to interfere with the proper action of the pump-valves; and the cages, when requisite, will be lifted above ground, by proper gearing, and the intercepted matter be discharged into trucks, or otherwise removed. The sewage will then pass into the wells, and be lifted by the pumps, through hanging valves, into a circular culvert of cast iron, and thence will be forced into any of the three culverts forming the Northern Outfall Sewers.

It is fortunate that these works were not projected in the year 1306, when coal was first introduced into London, and was regarded as such a nuisance, that the resident nobility obtained a royal proclamation to prohibit its use under severe penalties, for this pumping station alone will consume about 9,700 tons of coal per annum.

The cost of pumping is not, however, entirely in excess of the former expenditure upon the drainage; for the cost of removing deposit from the tide-locked and stagnant sewers in London formerly amounted to a sum of about £30,000 per annum; and the substitution of a constant flow through the sewers, by means of pumping, must necessarily largely reduce the deposit, and consequently the annual cost of cleansing.

The South Side of the Thames.

The High Level Sewer and its Southern Branch, correspond with the High and the Middle Level Sewers on the North side of the Thames. The Main Line commences at Clapham, and the Branch Line at Dulwich, and they together drain an area of about 20 square miles, including Tooting, Streatham, Clapham, Brixton, Dulwich, Camberwell, Peckham, Norwood, Sydenham, and part of Greenwich. Both lines are constructed of sufficient capacity to carry off all the flood-waters, so that they may be entirely intercepted from the low and thickly-inhabited district, which is tide-locked and subjected to floods. The storm-waters will be discharged into Deptford Creek, whilst the sewage and a limited quantity of rain will flow by four iron pipes, each 3 feet 6 inches in diameter, laid under its bed into the Outfall Sewer.

The two lines unite in the New Cross Road, near to the New Cross Station on the Brighton Railway, and they are constructed side by side along that road to Deptford; but at the New Cross Station, the Branch Line is 10 feet above the Main Line, but by falling at a more rapid inclination, it arrives at the same level as

the Main Line at Deptford Broadway. The Branch is $4\frac{1}{2}$ miles in length, of which 1,000 feet were executed in tunnel, at depths varying from 30 feet to 50 feet. Its size varies from 7 feet in diameter to a form 10 feet 6 inches by 10 feet 6 inches, with a circular crown and segmental sides and invert, and its fall varies from 30 feet per mile at the upper end, to $2\frac{1}{3}$rd feet per mile at the lower end. The soil through which it passes is mostly a mixture of sand and clay, containing cockle and other shells to a large extent. The old Effra Sewer, which fell into the river near Vauxhall Bridge, has been diverted through this sewer to a new outlet at Deptford, and the old line has been filled in and abandoned. Two subsidiary branches have been extended from this sewer at Dulwich—the one to Crown Hill, Norwood, and the other to the Crystal Palace.

The Main Line varies in size from 4 feet 6 inches by 3 feet at the upper end, to 10 feet 6 inches by 10 feet 6 inches, of the same form as the branch by the side of which it is constructed. The double line of sewer occupies the whole width of Church-street, Deptford, and the inverts being below the foundations of the houses on each side of the street, the walls of the houses were underpinned, and the spaces between them and the sewers filled in with concrete. The subsoil here consisted of loamy sand and gravel with large quantities of water, and, to add to the difficulty of the work, the old Ravensbourne Sewer, which passed through the centre of the street, had to be taken up, and its waters diverted during the progress of these operations.

The outlets of the two sewers, 10 feet 6 inches by 10 feet 6 inches, are each fitted with two hinged flaps, one above the other, the lower one being usually fixed close, so as to form a dam to drive the waters through the iron pipes into the Outfall Sewer, but the upper one hanging free, in order to serve as a tide flap, and allow of the exit of the sewage into the Creek, when it rises in the sewer to a sufficient altitude. In cases of heavy floods, however, the lower flap can be opened, to admit of a free and full discharge from the sewers into the Creek. The entrances to the iron pipes are in troughs, or sumps, in the large sewers, a short distance within or behind the outlet flaps, and are fitted with penstocks, to shut off the sewage from the Outfall Sewer in case of need.

The falls of the Main Line are, at the upper end 53 feet, 26 feet, and 9 feet per mile to the Effra Sewer at the Brixton Road, and thence to the outlet $2\frac{1}{3}$rd feet per mile. The sewer is executed in brickwork, varying in thickness from 9 inches to $22\frac{1}{2}$ inches, one-half, that forming the invert, being in Portland cement, and the remainder in blue lias mortar.

The whole of this line is completed, and has been in successful operation since January, 1863.

The Low Level Sewer (Plate 19) does not follow the course of the River, as on the North side, but, commencing at Putney, it takes a more direct line, through low ground once forming the bed of a second channel of the Thames, and drains Putney, Battersea, Nine Elms, Lambeth, Newington, Southwark, Bermondsey, Rotherhithe, and Deptford, comprising an area of 20 square miles. The surface of this area is mostly below the level of high water, and is, in many places, 5 feet or 6 feet below it, having at one time been completely covered by the Thames. The sewers throughout the district have but little fall, and, except at the period of low water, were tide-locked and stagnant; consequently, after long-continued rain, they became overcharged, and were unable to empty themselves during the short period of low water. The waters, therefore, were constantly accumulating, and many days frequently elapsed, after the cessation of the rain, before the sewers could be entirely relieved, the sewage in the interim being forced into the basements and cellars of the houses, to the destruction of much valuable property. The want of flow also caused large accumulations of deposit in the sewers, the removal of which was difficult and costly. These defects, added to the malaria arising from the stagnant sewage, contributed to render the district unhealthy; and it was with reference to the condition of this district, that the late Mr. R. Stephenson and Sir W. Cubitt so forcibly described the effect of artificial draining by pumping, as equivalent to raising the surface a height of 20 feet.

The Low Level Sewer has, in fact, rendered this district as dry and as healthy as any portion of the Metropolis. Its length is about 10 miles. Its size varies from a single sewer 4 feet in diameter at the upper end, to two culverts, each 7 feet high by 7 feet wide, at the lower end, and its fall ranges from 4 feet to 2 feet per mile. The lift at the outlet of the sewer is 18 feet. This sewer was constructed through a stratum of sand and gravel overlying the clay, such as is frequently found in the beds of rivers, and copiously charged with water. Some very successful instances of tunnelling under canals, railways, and house property, occurred in the construction of this work; and a mode of pumping in a quicksand, and rendering it dry and firm without drawing off the sand, was adopted, which will be more particularly described in another part of this Paper. Much difficulty was experienced in executing a portion of this work close to and below the foundations of the arches of the Greenwich Railway, and under Deptford Creek, owing to the large volume of water there met with. This was, however, at last surmounted, by sinking two iron cylinders, each 10 feet in diameter, through the sand, to a depth of about 45 feet, the water being kept down by pumping, at the rate of from 5,000 gallons to 7,000 gallons per minute. The sewer was carried under

Deptford Creek, and the navigation was kept open, by constructing a coffer-dam into the middle of the Creek, and by executing one-half of the work at a time. All these works were completed with but few and unimportant casualties.

The sewers of this district had been constructed, generally, with a fall from west to east, and had been connected with each other in such a manner that, in case of one becoming first overcharged, it might be relieved by its neighbour, and the sewage be reduced to a uniform level all over the district. Taking advantage of this circumstance, an important branch was constructed from the Low Level Sewer at High-street, Deptford, towards the river to St. James's Church, Bermondsey. This branch, by intersecting the Earl, the Duffield, and the Battle Bridge Main Sewers, relieves a large and populous district. Its length is about 2 miles, its size varies from 5 feet to 5 feet 6 inches in diameter, and its fall is $4\frac{1}{2}$ feet per mile. Its depth varies from 15 feet to 40 feet below the surface, and it has been in successful operation since January, 1864.

The Deptford Pumping Station is situated by the side of Deptford Creek, and close to the Greenwich Railway Station. The sewage is here lifted from the Low Level Sewer, a height of 18 feet, into the Outfall Sewer. An iron wharf wall and barge bed, 500 feet long, has been constructed at the side of the creek, and is provided with a crane and tramways, for landing coal or other materials. Four expansive, condensing, rotative beam engines, each of 125 H.P., and capable together of lifting 10,000 cubic feet of sewage per minute a height of 18 feet, are here constructed. These engines are worked by ten Cornish single-flued boilers, each 30 feet long and 6 feet in diameter. The cylinders are 48 inches in diameter, with a length of stroke of 9 feet, and the pumps, two of which are worked by one engine direct from the beam, are single-acting plunger pumps, the diameter of the plungers being 7 feet and the length of the stroke $4\frac{1}{2}$ feet. One pump is placed on the beam, midway between the steam cylinder and the centre pillars, and the other midway between the centre pillars and the fly wheel. The air, the feed, and the cold water pumps are actuated by a separate beam, attached to the cylinder end of the main beam. The pump valves are leather-faced hanging valves, and the sewage is discharged through them into a wrought-iron culvert placed on the level of the Outfall Sewer, and connected with it by a brick culvert, which receives also the sewage from the High Level Sewer, previously brought by gravitation under the creek, through four cast-iron pipes 3 feet 6 inches in diameter. Both streams enter the Outfall Sewer, and are together conveyed to Crossness, where they are again lifted. The chimney shaft at this station is $7\frac{1}{2}$ feet in diameter at the base and 6 feet at the top;

its height is 150 feet, and the furnaces draw from the sewers and the engine-well to assist in the ventilation of the works. The accommodation for coals is ample, the sheds covering an area of 18,000 superficial feet.

Provision is made, by gratings, for the interception of the larger substances brought down by the sewers, in the same manner as at Crossness.

This Station is completed, and the engines have been in operation since May, 1864.

The Southern Outfall Sewer conveys the sewage which flows into it from the High Level Sewer by gravitation through the four iron culverts laid under Deptford Creek, and that which is pumped into it from the Low Level Sewer, from Deptford through Greenwich and Woolwich to Crossness Point in the Erith Marshes. It is not, like the Outfall Sewer on the North side, constructed above the level of the ground, but is entirely under ground for its whole length of $7\frac{3}{4}$ miles. It is 11 feet 6 inches in diameter, formed in brickwork generally 18 inches thick, and has a fall of 2 feet per mile. The bottom of the sewer is 9 feet below the level of low water at its outlet into the river, so that it can discharge into the river at and near to low water, by gravitation, in case of necessity; but ordinarily the mode of discharge will be by pumping into the Crossness Reservoir. It has been constructed at a depth of about 16 feet below the surface, except through Woolwich, where the depth ranges from 45 feet to 75 feet. The soil through which it passes is mostly gravel and sand, but the Woolwich tunnel, which is the principal feature of the work, is partly in the chalk. One mile of this tunnel was executed under the town of Woolwich, without any casualties or settlements.

The large volume of water met with in the Marshes, rendered the construction of that portion of the work very costly. These marshes originally formed part of the Thames, and were first enclosed in the reign of Edward I., by the monks of Lesnes Abbey; 2,000 acres were afterwards flooded, by the bursting of the river banks, in the reign of Henry VIII., and were not again reclaimed until the reign of James I. They would have suffered a similar fate, in the year 1864, in consequence of the breach caused in the river bank by the explosion at Messrs. Hall's Powder Magazine, had not a large number of workmen then engaged upon the Main Drainage works at Crossness, at once, by prompt and energetic efforts, afterwards efficiently aided by the military, repaired the breach before the rising of the following tide.

This sewer was completed in June, 1862, and has been in successful operation since that period.

The outfall of the sewage on the South side of the Thames is at

the Crossness Reservoir and Pumping Station. The sewage is discharged into the river at the time of high water only, but the sewer is at such a level, that it can discharge its full volume by gravitation about the time of low water. Its outlet is ordinarily closed by a penstock placed across its mouth, and its contents are raised by pumping into the reservoir, which is built at the same level as that on the North side; and, like it, it stores the sewage, except for the two hours of discharge after high water. The sewage is thus diverted from its direct course to the river, into a side channel leading to the pump-well, which forms part of the foundation for the engine-house; from this well it is lifted by four beam engines, each of 125 H.P., and actuating, direct from the beam, two compound pumps, each having four plungers. The engines are condensing, rotative beam engines, the cylinders being 4 feet in diameter, with a length of stroke of 9 feet; they are situate at the end of the main beam, which is 40 feet in length, the fly-wheel connecting rod being attached to the further extremity, and the pump rods situate on either side of the beam centre. The air, the feed and the cold-water pumps are actuated by a separate or counter beam, fixed at one end to a rocking lever, and attached at the other to the main beam. The cylinders are supplied from twelve Cornish boilers, each 6 feet in diameter and 30 feet long, having an internal furnace and flue 3 feet in diameter, and being set so as to have the second heat carried with a split draught along the sides, and the third heat under the bottom of the boiler into the main flue leading to the chimney.

The maximum quantity of sewage to be lifted by these engines will ordinarily be about 10,000 cubic feet per minute; but during the night, that quantity will be considerably reduced, while on the other hand it will be nearly doubled on occasions of heavy rainfall. The lift also will vary from 10 feet to 30 feet, according to the level of water in the sewer and in the reservoir into which it is lifted. These variable conditions of working led to some difficulty in the arrangement of the engines and pumps, which it has been endeavoured to meet by the arrangement of pump plungers before alluded to. The pumps, which are single-acting, are placed equidistantly on each side of the beam centre, the pump cases being each 12 feet in diameter, fitted with four plungers 4 feet 6 inches in diameter. These plungers are placed in pairs, each pair being worked from a cross-head on the main beam, which is in two flitches with this object, and arrangements are made for throwing either pair of plungers out of gear. By these means the capacity of the pumps may be varied, in the proportion of 1, 2, or 3, as the inner pair, outer pair, or both pairs are thrown into gear. The sewage is discharged into a wrought-iron trough, through hanging leather-faced valves, which are suspended from wrought-iron shackles, and fitted with the wrought-iron back and front plates. Each valve is

12 inches by 18 inches. It should be mentioned, that substances which might prevent the proper action of the valves are intercepted before reaching the pumps, by a wrought-iron grating placed in front of the openings to the pump well, the substances so intercepted being lifted from the face of the grating by an endless chain, with buckets or scrapers and combs attached, working vertically in front of and in close contact with the grating, the teeth of the comb passing between the bars. On the descent of the chain, the buckets are overturned and discharge their contents into a trough, from which they will be removed by manual labour.

The sewage, after being delivered from the pumps into the wrought-iron trough, is discharged through brick culverts into the reservoir, or, in case of need, provision is made for its discharge through other culverts directly into the river. After being stored in the reservoir until the time of high water, the sewage is discharged by a lower set of culverts into the river. There are two tiers of eight openings in each compartment of the reservoir, the upper eight for the admission of the sewage from the pumps to the reservoir, and the lower eight for its discharge into the river, the apertures in all cases being opened and closed by penstocks.

The reservoir, which is $6\frac{1}{2}$ acres in extent, is covered by brick arches supported on brick piers, and is furnished with weirs for overflows, and with a flushing culvert. Its height, level, and general construction are similar to that at Barking Creek, already described. Over the reservoir are built twenty-one cottages, for the engineers and other persons employed upon the works.

The ground upon which the whole of these works were constructed consists of peat, sand, or soft silty clay, and affords no sufficient foundation within 25 feet of the surface. To obviate this difficulty, and to reduce the expense of the foundations as much as possible, the culverts on the various levels were built, as far as practicable, in the same trenches, one above the other; the lowest, leading from the Outfall Sewer to the pump-wells, support those discharging the sewage from the reservoir, which latter in turn support those leading from the pumps into the reservoir. The requirements of the pump-wells necessitated that the walls of the engine-house should be carried down to the level of the gravel, independently of the nature of the ground; but such was not the case with the boiler-house. The boilers and stoke-hole floor are supported on arches, which spring from walls brought up from the gravel, and the space below the boiler-house floor is made available as a reservoir for condensing water. The water from the hot and cold wells of the engines is conveyed hither, and one compartment is set apart as a chamber for cooling the water from the hot well, previous to its being used again for condensing water. With the same object, of saving separate foundations, coal stores and workshops have been erected, partly on the external walls of the

reservoir, and partly on the culverts in front of them, large coal stores being also provided in front of the boiler-house, and on a level with the stoke-holes, into which the coals will be brought on tramways. A tramway is also provided for the upper level coal-sheds, on the level of the tops of the boilers, whence the coals will be shot into the stoke-holes below. Tramways are also laid from the coal-sheds to the river, and jetties are carried out into the river, to facilitate the landing of coals, and their transfer to the stores. A wharf wall has been constructed along the river frontage of the works, for a distance of about 1,200 feet, by which a large portion of the 'saltings' has been reclaimed. The wall is of brick, carried upon brick arches, which rest upon piers formed of iron caissons filled with concrete, and which are carried down to the gravel.

The chimney into which the flues from the boilers are conveyed is square on plan externally, being 8 feet 3 inches internal diameter throughout, and 200 feet in height; it is founded upon a wide bed of concrete, brought up from the gravel, which is here 26 feet below the surface.

The reservoir, as well as the several culverts and the pump wells, are all connected by flues with the furnaces of the boilers, for the purposes of ventilation, in a manner similar to that adopted at the Deptford and other pumping stations.

The outlet into the river from the Outfall Sewer, which was constructed in connection with these works, consists of twelve iron pipes, each 4 feet 4 inches in diameter, carried under the 'saltings' into a paved channel formed in the bed of the river. These pipes are gathered into the single sewer, by culverts in brickwork on the land side of the wharf wall, the culverts being gradually reduced in number, and their dimensions increased, as they approach the junction with the large Outfall Sewer. The whole of these works have recently been completed.

The tunnels successfully completed (Plates 20, 21, and 22), under circumstances of difficulty, and where failure would have been very disastrous, were numerous.

The tunneling, and the formation of the sewers through quicksands charged with large volumes of water, existing under various portions of the metropolis, but more particularly in the low-lying districts on the south side of the Thames, were rendered practicable and safe, by a mode of pumping the water out of the ground, without withdrawing the sand, which was adopted and perfected during the progress of these works.

During the Author's early connection with the Metropolitan Sewers, several disastrous results of pumping in quicksands had occurred, in consequence of the withdrawal of the sand from under the foundations of the adjoining houses. This caused

unequal settlements and fissures in the walls, so that the buildings had eventually to be pulled down and rebuilt. The Victoria-street Sewer through Scotland-yard is perhaps one of the most serious instances of this kind; portions of the War Office, Fife House, the United Service Museum, the Office of Works and other valuable property were then more or less injured. One of the first works executed by the Author, upon his appointment, was the reconstruction of this sewer, from which a branch sewer was subsequently constructed from it, through the same soil, close underneath the Clock Tower of the Horse Guards, without the slightest damage to that important and heavy building.

The sewers in Tothill Street, Duke Street, and other streets in the neighbourhood of Great George Street, Westminster, being in peat and sandy soils charged with water, were not formed without considerable risk. The late Mr. Brunel was at one time under serious apprehension lest his residence should subside into the peat on which it stands, the sewer trench having been opened to a great depth close to it; and he afterwards expressed much satisfaction at the precautions adopted to obviate such a catastrophe.

The cases are too numerous to be here mentioned, but a few of the more prominent may be alluded to. The line of tunnel from Kennington Church to the Old Kent Road, a distance of about 1,000 feet, is close under the basements of a large number of houses, the top of the tunnel being only from 10 feet to 12 feet below the surface, and the diameter being about 10 feet. The water was pumped out of the sand, for this length of tunnel, at the rate of about 8,000 gallons per minute. The same sewer was carried, through similar soil, under the Grand Surrey Canal, and within 8 feet of the water in it; and again under the same canal in the Deptford Lower Road, where the distance between the top of the tunnel and the water in the canal was only 6 feet 4 inches, the whole of the soil being gravel and sand, with 1 foot of puddle in the bottom of the canal.

The Regent's Canal in the Caledonian Road was also tunnelled under, the distance between the top of the tunnel and the water in the canal being only 2 feet, so that the miners could hear the barges as they passed over their heads scrape against the ground; this was, however, executed in clay. Another tunnel has been formed 33 feet under the rails of the West London Railway, and under the Kensington Canal. Sewers were constructed, under the London and Brighton, the North Kent, and several other railways, without any interruption to the continuous traffic on them.

The method adopted for pumping out the water, without drawing off the sand, and for building the brickwork in ground so charged with water, was first to sink, in some convenient position,

near the intended works, a brick well to a depth of 5 feet or 6 feet below the lowest part of the excavation. In some cases, where the depth was great, an iron cylinder was sunk below the brickwork, and the bottom and sides of the well were lined with shingle, which filtered the water passing into it, and exposed a large surface of this filtering medium. Earthenware pipes were carried from this well and laid below the invert of the intended sewer, small pits being formed at the mouths of these pipes, to protect them from the deposit. By these means, the water has been successfully withdrawn from the worst quicksands, and they have been rendered firm and dry for building on. Iron plates have, in olden times, been laid underneath the brickwork of the invert of the sewers, to support them in such treacherous ground, but concrete forms both a cheaper and a better foundation, and unless the ground is so dry and solid that it can be excavated to the exact form of the sewer to be placed on it, there is no portion of the work more important, than the effectual backing of the invert and the haunches with concrete.

The bricks used in the works have been mostly picked stocks and Gault clay bricks, and the inverts were occasionally faced with Staffordshire blue bricks. The brickwork is laid in blue lias lime mortar, mixed in the proportions of 2 of sand to 1 of lime for one-half or two-thirds of the upper circumference of the sewers, and the remainder has been laid in Portland cement, mixed with an equal proportion of sand. A very considerable length of sewer has been laid entirely in cement. A double test of the quality of the cement has been used, which has been found most effective, and has tended greatly to improve the manufacture of that material, so important in building operations. The specifications provide, that the whole of the cement shall be Portland cement of the very best quality, ground extremely fine, weighing not less than 110 lbs. to the bushel, and capable of maintaining a breaking weight of 500 lbs., on $1\frac{1}{2}$ square inch, seven days after being made in an iron mould, and immersed in water during the interval of seven days.

The total cost of the Main Drainage Works, when completed, will have been about £4,100,000. The works have been executed under the immediate superintendence of the Assistant Engineers, Messrs. Lovick, Grant, and Cooper. The principal contractors have been Messrs. Brassey, Ogilvie, and Harrison; Mr. Webster; Mr. Furness; Messrs. Aird and Sons; Mr. Moxon; Messrs. James Watt and Co.; Messrs. Slaughter; and Messrs. Rothwell and Co. The sum for defraying the cost of these works is raised by loan, and paid off by a 3*d.* rate levied on the metropolis, which produces £180,262 per annum, the ratable value

being £14,421,011, and the principal and interest of the loan will be paid off in forty years.

There are about 1,300 miles of sewers in London, and 82 miles of main intercepting sewers. Three hundred and eighteen millions of bricks, and 880,000 cubic yards of concrete have been consumed, and $3\frac{1}{2}$ million cubic yards of earth have been excavated in the execution of the Main Drainage Works. The total pumping power employed is 2,380 nominal H.P.; and if at full work night and day, 44,000 tons of coals per annum would be consumed, but the average consumption is estimated at 20,000 tons.

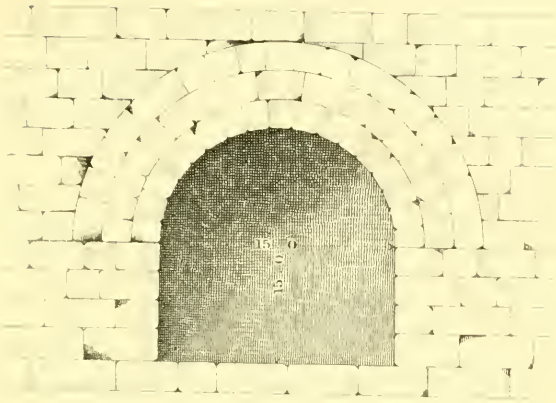
The sewage on the North side of the Thames at present amounts to 10 million cubic feet per day, and on the South side to 4 million cubic feet per day; but provision is made for an anticipated increase up to $11\frac{1}{2}$ million on the North side, and $5\frac{3}{4}$ million on the South side, in addition to $28\frac{1}{2}$ million cubic feet of rainfall per diem on the North side, and $17\frac{1}{4}$ million cubic feet per diem on the South side, or a total of 63 million cubic feet per diem, which is equal to a lake of 482 acres, 3 feet deep, or fifteen times as large as the Serpentine in Hyde Park.

The whole of the Main Drainage scheme is now completed, with the exception of the Low Level Sewer on the North side of the Thames, which is being formed in conjunction with the Thames Embankment and the new street to the Mansion House, and will therefore probably not come into operation for two years. The proportion of the area drained by that Sewer is one seventh of the whole. Some sections of these works have been completed, and have been in working operation, from two to four years, and the largest portion of the work has been completed and has been in operation for more than a year, so that the principles upon which the scheme has been based have already been fairly tested.

The communication is accompanied by numerous Appendices, including Tables of Rainfall, particulars of many instances of tunneling, as well as a list of the fossil remains, antiquities, &c., found in excavating for the works.[1] It is illustrated by a Map of London, and by models and enlarged diagrams of some of the principal works, from which Plates 14 to 22 have been compiled, as well as by a complete set of the specifications and of the contract drawings, which is presented to the Institution by the Author.

[1] A very large number of ancient animal remains, curiosities, and coins were found in different portions of the work; many of these were sold by the workmen and were not given up to the Board. Most of them may be seen at the British Museum. They consist chiefly of the bones of elephants, whales, and the horns of deer and oxen, with some flint implements of war and ancient human skulls, stone and leaden coffins, and a number of Roman coins of various reigns.

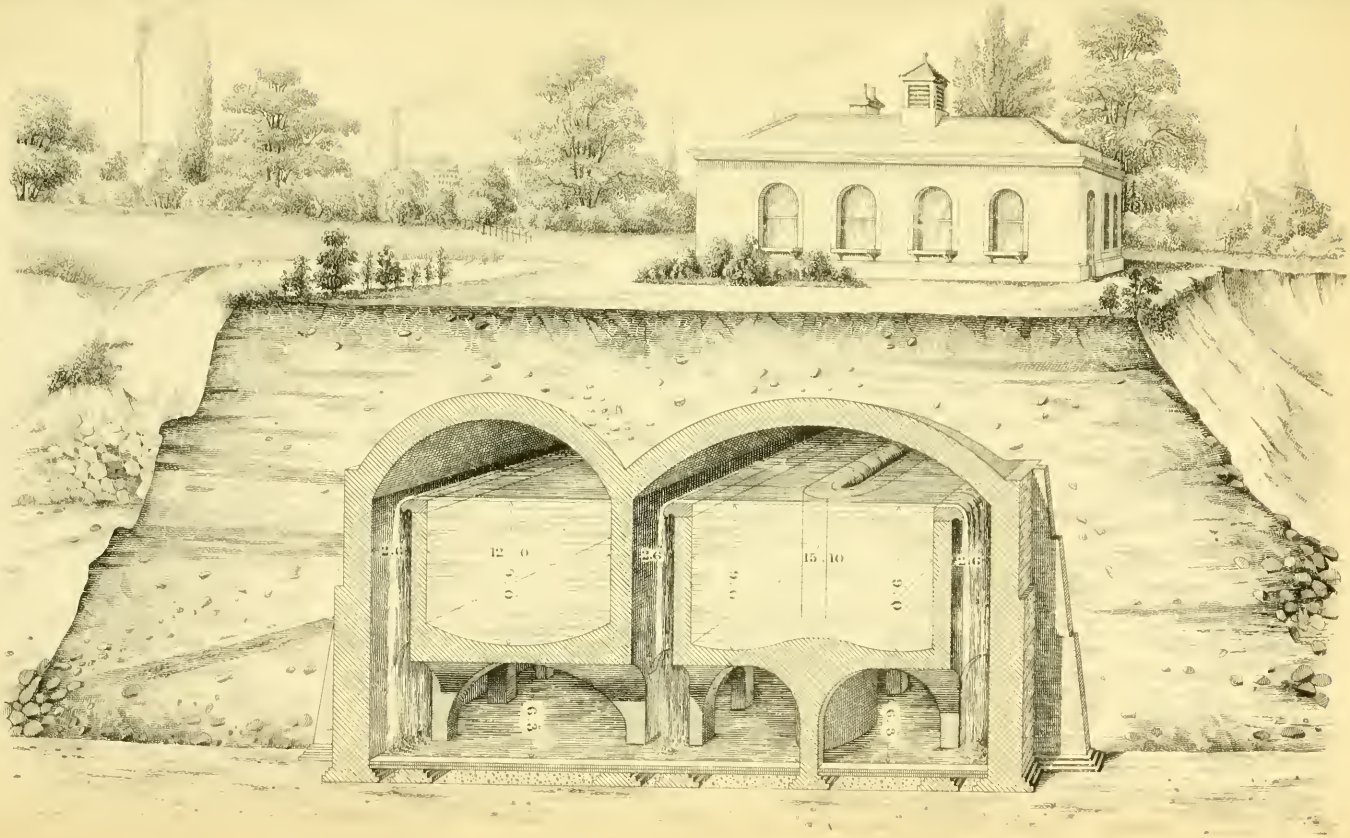
HIGHGATE
HAMPSTEAD
WILLESDEN
WEST END
SOUTH END
KENTISH TOWN
UPPER HOLLOWAY
LOWER HOLLOWAY
HIGHBURY
KINGSLAND
DALSTON
HOMERTON
HACKNEY WICK
UPPER CLAPTON
LOWER CLAPTON
STOKE NEWINGTON
LOW LEYTON
LEYTON STONE
ILFORD
LITTLE ILFORD
HARLESDEN
KILBURN
ISLINGTON
HOXTON
STRATFORD
OLD FORD
WEST HAM
ABBEY MILLS
BOW
BARKING
PADDINGTON
EAST ACTON
BAYSWATER
NOTTING HILL
STARCH GREEN
ACTON BRANCH
HAMMERSMITH
CHISWICK
KENSINGTON
BROMPTON
PIMLICO
CHELSEA
WESTMINSTER
VICTORIA
REGENTS PARK
EUSTON
KINGS CROSS
ST PANCRAS
FARRINGDON
SMITHFIELD
BISHOPSGATE
HAYDON SQR
ALDGATE
MINCING LANE
HYDE PARK
GREEN PARK
ST JAMES'S PARK
CHARING CROSS
WATERLOO
BLACKFRIARS
LONDON BRIDGE
BRICKLAYERS ARMS
NEWINGTON
KENNINGTON
WALWORTH
ST LAMBETH
BATTERSEA PARK
NINE ELMS
VICTORIA
CAMBERWELL
PECKHAM
PECKHAM RYE
NEW CROSS
GREENWICH
GREENWICH PARK
DEPTFORD
ROTHERHITHE
ISLE OF DOGS
LIMEHOUSE
POPLAR
STEPNEY
BROMLEY
MILE END
PLAISTOW
EAST HAM
PLAISTOW MARSH
EAST HAM LEVEL
BARKING LEVEL
BARKING CREEK
RESERVOIR
CROSSNESS
LIFT & RESERVOIR
NORTH WOOLWICH
VICTORIA DOCKS
ROYAL ALBERT
NEW CHARLTON
GREENWICH MARSHES
CHARLTON
WOOLWICH
PLUMSTEAD
PLUMSTEAD MARSH
ABBEY WOOD
BARRACK FIELD
WOOLWICH COMMON
ARTILLERY PRACTICE GROUND
ORDNANCE
BLACKHEATH
UPPER KIDBROOKE
LOWER KIDBROOKE
SHOOTERS HILL
EAST WICKHAM
WELLING
LEE
LEWISHAM
BROCKLEY
CROFTON PARK
BRIXTON
CLAPHAM
CLAPHAM COMMON
WEST BRIXTON
EAST DULWICH
CHAMPION HILL
DULWICH
FOREST HILL
SYDENHAM
BELL GREEN
LOWER SYDENHAM
CRYSTAL PALACE
STREATHAM
LOWER NORWOOD
UPPER STREATHAM
UPPER TOOTING
TOOTING
WIMBLEDON
WIMBLEDON COMMON
WIMBLEDON PARK
BALHAM HILL
PUTNEY
WANDSWORTH
ROEHAMPTON
FULHAM
BARNES
WALHAM GREEN
BUSHEY GREEN
SOUTH END
ELTHAM
ELTHAM GREEN
BLEEDON
SOUTHEND
POPE STREET
LAMB ABBEY
COLD HARBOUR
NORTH CRAY
FOOTS CRAY
NORTHERN HIGH LEVEL SEWER
NORTHERN OUTFALL SEWER
MIDDLE LEVEL SEWER
LOW LEVEL SEWER
SOUTH BERMONDSEY BRANCH SEWER
SOUTHERN OUTFALL SEWER
WESTERN MAIN LINE SEWER
HACKNEY BRANCH
HACKNEY CREEK BRANCH
ISLE OF DOGS BRANCH
PICCADILLY BRANCH
FULHAM BRANCH
EFFRA BRANCH
METROPOLITAN RAILWAY
GREAT WESTERN RAILWAY
LONDON & NORTH WESTERN RAILWAY
GREAT EASTERN RAILWAY
LONDON & BLACKWALL RAILWAY
LONDON BRIGHTON & SOUTH COAST RAILWAY
LONDON CHATHAM & DOVER RAILWAY
SOUTH EASTERN RAILWAY
SOUTH WESTERN RAILWAY
WEST LONDON & CRYSTAL PALACE RAILWAY
NORTH KENT RAILWAY
LONDON & BLACKWALL RAILWAY
LIFT
Scale of Miles



CLOACA MAXIMA
ROMA

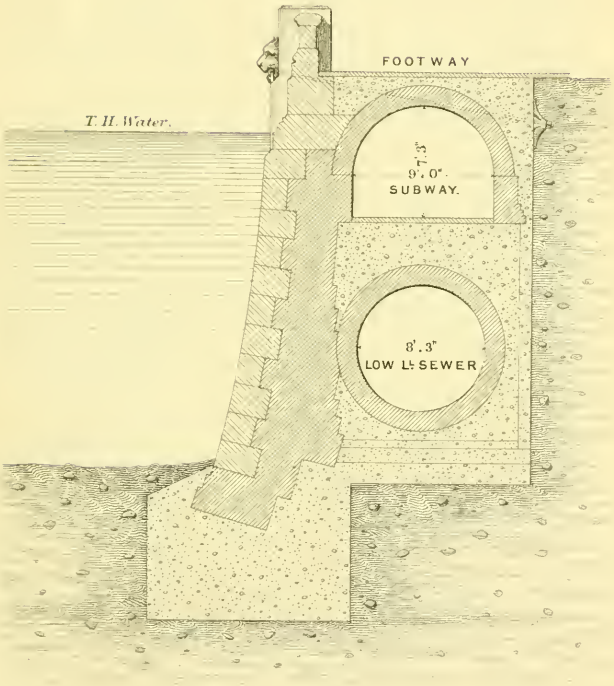
RANELAGH SEWER, CHELSEA.
1809.

EAST ELEVATION OF PRIVATE BRIDGE



SECTION OF OVERFLOW CHAMBER AT JUNCTION OF NORTHERN HIGH & MIDDLE LEVEL SEWERS.

NORTH SIDE.



SECTION OF THAMES EMBANKMENT, SUBWAY & LOW LEVEL SEWER.

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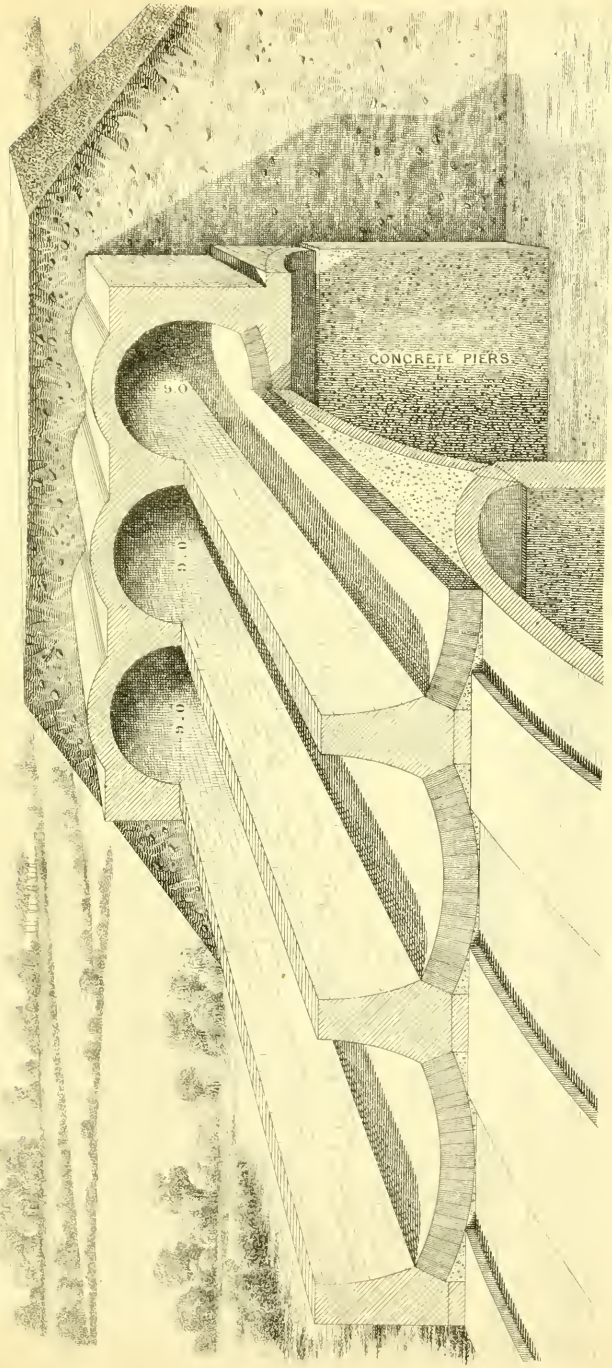
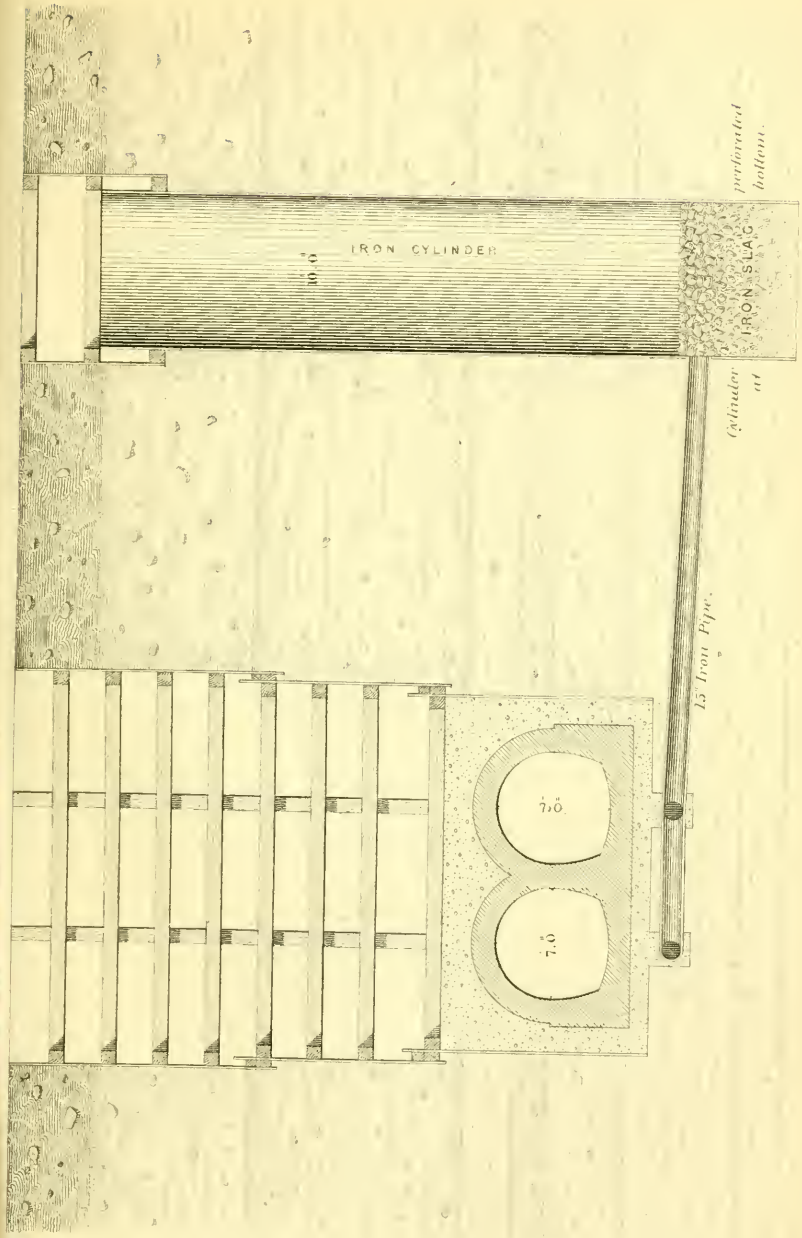
J.W. BAZALGETTE DELT KELL. BROS



NORTHERN OUTFALL SEWER. SECTION OF EMBANKMENT, CULVERTS AND SUBSTRUCTURE.

W. BALLANTYNE DEL.



LOW LEVEL SEWER AT GAS WORKS, DEPTFORD. TRANSVERSE SECTION OF SEWER & SUMP.

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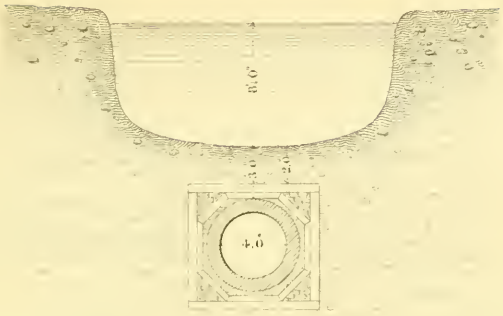
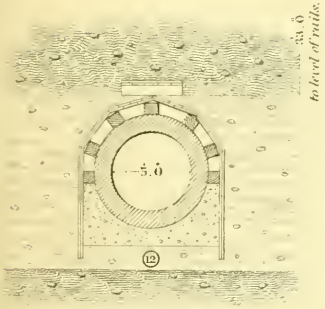
GAILGETTE PLATE

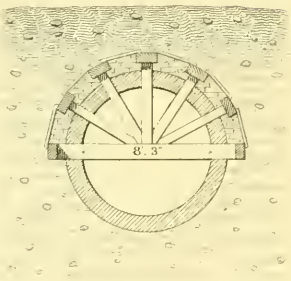
KELL BROS



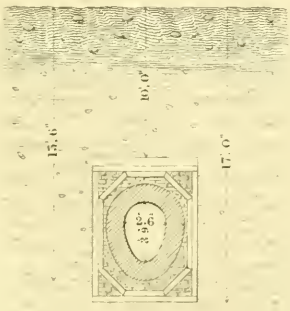
SECTION OF SEWER IN TUNNEL UNDER REGENT'S CANAL, CALEDONIAN ROAD.



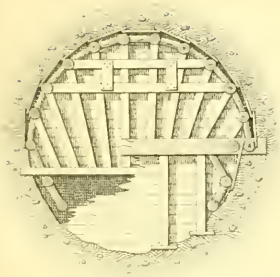
SECTION OF SEWER IN TUNNEL UNDER
EST LONDON RAILWAY, NEAR FULHAM GAS WORKS.



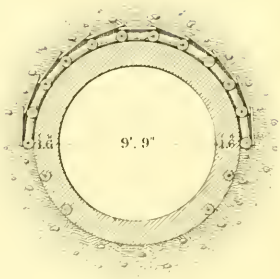
SECTION OF SEWER IN TUNNEL
UNDER NEW RIVER EMBANKMENT.



SECTION OF SEWER IN TUNNEL UNDER HORSE GUARDS.

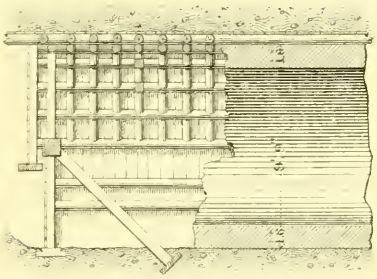


LOOKING WEST.



LOOKING EAST.

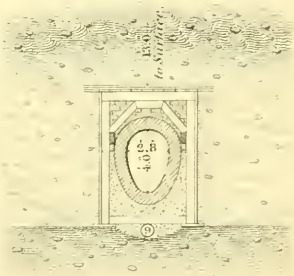
TRANSVERSE SECTIONS.



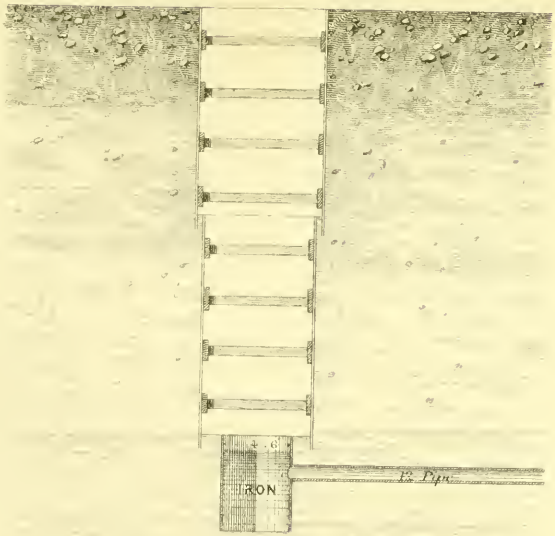
LONGITUDINAL SECTION.

MIDDLE LEVEL SEWER. TUNNEL UNDER NEW INN YARD.

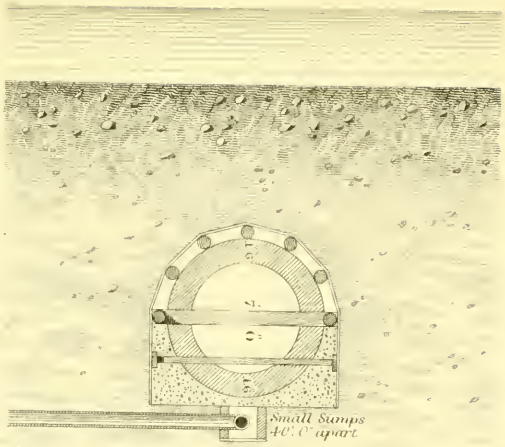
SECTION OF SEWER IN TUNNEL
NEAR THE UPPER MALL, HAMMERSMITH.



SECTION OF SEWER IN TUNNEL
UNDER QUEEN STREET, HAMMERSMITH.



SECTION OF SUMP,
OLD KENT ROAD, NEAR GRAND SURREY CANAL



SECTION OF SEWER IN TUNNEL
UNDER GRAND SURREY CANAL.

Mr. BAZALGETTE said, that he had no further information to add to his Paper on the Main Drainage of London. With respect to the Drainage of Paris, it appeared from the Paper on that subject, that there were about 217 miles of sewers of all kinds in Paris, or about one-sixth of the length of sewers in London. A large number of the streets in Paris had a sewer on each side of the street, so that it might be fairly assumed, that the length of streets drained by sewers in Paris was only one-tenth of the whole length drained in London. Then again, the sewers of Paris carried off the liquid refuse only, and not the solid: thus the system was very complicated. There was a large number of cesspools requiring to be cleansed by manual labour; and those acquainted with Paris must be aware, that many of the streets were drained on the surface, in a most offensive and objectionable manner. The cost of constructing sewers in that city, ought to have been much cheaper than in London, because a smaller city could always be drained at a cheaper rate than a larger city. The sewage of the smaller one had not to be carried so far: it did not accumulate in such large masses, and the sewers could therefore be constructed *pro rata* of smaller dimensions, and at a smaller cost. The greater width of many of the streets, and the smaller amount of traffic, was another reason why the sewage of Paris should have been proportionately more economical than that of London; but that was not so, as the cost of constructing the sewers for a given length of street had been much in excess of the average cost of constructing the sewers of London. It had been stated, that the cost of maintenance was £30,000 per annum; whether that sum included the cost of cleansing the cesspools did not appear; but at the same rate, the cost of maintaining the London sewers would be £180,000 per annum. He was not, however, surprised at this great difference, when he learnt that the smallest size of sewer now used in Paris was 5 feet 6 inches by 3 feet. He had never been favourable to the system of extremely small sewers, at one time advocated and adopted, but, he considered, that the Parisians had gone to the opposite extreme. The perfection of Engineering was to have the capacity of a work exactly adapted to the duty it had to perform. By constructing sewers of such great size, with so small a fall, they were prevented carrying off the deposit which they were intended to remove. Those considerations would account for what, at first sight, must appear an anomaly. In Paris, the minimum fall of the sewers was 1 in 1000, or about 5 feet to a mile, and yet the sewers collected deposit. In fact, it would appear that instead of constructing the sewers so as to carry off the deposit, great ingenuity had been expended in inventing appliances to cleanse them by artificial means. Surely the necessity for those appliances

indicated that there must be some radical defect in the construction of the sewers; or how was it to be accounted for, that sewers with a fall of 5 feet to a mile, collected deposit, and had to be cleansed at great cost, while the Northern Outfall Sewer of London, which had only a fall of 2 feet to the mile, required no artificial cleansing? That sewer had now been in operation more than a year and a half, and the invert was quite clear of deposit. In designing sewers, the object to be attained was, to get such a velocity of flow through them as would be sufficient to keep them clean. The section of the sewer carried through the Boulevard de Sebastopol showed, that at least two-thirds of its area was utilized only to accommodate two water-pipes. It was an enormous cost to pay for such an arrangement, which when effected appeared to him most inconvenient. The pipes were placed on costly brackets almost at the top of the sewer, at a point where there was difficulty in getting at the joints to repair leakage, or form connections. For these and other reasons, which would occur to Drainage Engineers, he thought the works of drainage in Paris did not afford an example either of economy, or efficiency.

Mr. G. R. Burnell said, at first sight it might appear that the sewerage of Paris was designed as much for the relieving of the houses as for the relieving of the streets; but in that city, on the contrary, not any of the house-sewage was admitted into the drains. The fact was, that the French people regarded the sewers as performing a different function to that which the English Engineers considered necessary. The Paris sewers were constructed to carry off the road sweepings, and the storm and surface waters, and therefore were of greater sectional area than the London sewers. As regarded the drainage of London, he believed, that almost all the matter which was deposited in the River Thames came from the sea, and not from the land, and therefore, when the drainage-works were executed, it would be found, that all the matters which were deposited from the sewers would find their way back again to London, as much as they did at present. It was to be regretted, that the Author of that Paper had not stated the difference between the estimated amount of the contract, and the actual cost of the works. The estimated amount of the contract was about £2,130,000, whereas, the actual cost of the works executed had been about £4,100,000, and yet the works of the low-level sewers were still incomplete. Those facts required a little explanation. As regarded the execution of the works, he would notice, that the specimen of Portland cement, which had been exhibited, had considerably swollen since it first set. If the cement which had been used for the works was in a similar condition, it would not argue well for their duration. The test which had been imposed upon the cement was not of the same character

as the exigencies of the works required. It was a test only of pure cement, and not a test of cement mixed with sand. In such a case it would have been better to have employed the test used by the French Engineers, namely, that of mixing one part of sand and one of cement, and then applying to it a pressure of 144 lbs. on the square inch. The results given in the Paper ought not to be taken as affording an indication of the extent to which the sewers might be affected, after some time had elapsed. In conclusion, he submitted a specimen of M. Coignet's béton, which had been alluded to in the account of the Drainage of Paris.

Mr. Robert Rawlinson said, that reference had been made in the Paper on the Main Drainage of London, to certain formulæ which, it was stated, were applicable to the construction of sewers. In his opinion, however, no formulæ existed, which Engineers could use, for the apportionment of the cross sectional dimensions of sewers. To talk of a formulæ for main sewers, devised and drawn up from any one set of experiments, would only tend to mislead young Engineers. There were no two places which required precisely the same treatment. In the case of the Metropolitan Drainage, the whole water supply had been taken on the two sides of the Thames, and the intercepting sewers were made on the south side for four times the present volume, and on the north side for three times that volume, while flood-water outlets were made to deliver surface water out of the sewers down into the natural channel of the river. That was a method which might be studied with advantage, and in some form be applied in other districts. The proper mode of proceeding was:—before attempting to fix the dimensions of main sewers, to take the area to be operated upon as it existed; to consider what nature had previously done with that area: then to consider the special duties which the sewers had to perform, and apportion them to the water supply and to the probable increase of the population; and if the dimensions adopted were calculated for passing off three times, or four times that volume, the Engineer would not be far astray in his calculation. The rainfall, as rainfall, had very little to do with the question. There might be a rainfall, as in England, varying from 17 inches per annum, on the eastern coast, to 150 inches per annum, in some of the hill districts of Cumberland; and in town districts, it might range from 20 inches to 50 inches; while in parts of India, the rainfall, during the monsoons, was from 150 inches per annum, to 300 inches per annum. He discarded altogether, in his calculations, the question of these excessive rainfalls, as the discharge of such large volumes of rainwater must continue to be over the surface, or by large overflows from the sewers, to natural streams, or valley lines. Sewers large enough for men to enter, merely to cleanse them, were not necessary, and he believed it to be possible

so to deal with different districts by constructing small or egg-shaped sewers as to make them work without great difficulties. Where sewers had been made of sufficient capacity for men to enter them, and with flat inverts, it had been found in practice that such sewers required to be regularly cleansed, because the excessive dimensions and flat inverts retained all solids, until removed by hand-labour at great cost. As regarded the metropolitan main sewerage, the most difficult task would be, to revise, renovate, and reconstruct the 1,300 miles of old sewers which already existed; many miles of which were in ruins and choked with filth to such an extent that no ordinary application of water could remove it, and which, at great labour and expense, had now to be removed by shovels. When main sewers were well graded, and made of proper cross sectional form, and properly constructed, they were self-cleansing. In a city, or town that was sewered on proper principles, it was absolutely impossible for rats to exist, because they could not find either food, or lodging. The periodical battues upon rats was the strongest evidence of the inefficiency of the Parisian system. It had been stated that the modern system of sewerage in Paris was not intended to take away the house-sewage. The Parisians committed the fatal mistake, about the year 1820, of insisting, by ordinance, on cesspool construction. It was recorded that the whole sub-soil of Paris was on the point of becoming putrid with cesspit matter, and that the ordinance was passed in consequence. By it, all cesspits, as matters of private construction, were abolished, and the construction of cesspools upon a gigantic scale was undertaken, or dictated by the municipality, and all persons thereafter building hotels, or houses were obliged to construct "hermetically-sealed cesspools" after a municipal or royal pattern, which had been devised by the Government Engineers of France. Into those cesspools effete matter from water-closets, grease and washings from the sinks, and other such refuse was to be discharged. He considered Paris, when he visited it twelve years or fourteen years ago, to be, on the surface, perhaps, the cleanest city in the world. Nothing could be more beautiful than the order and cleanliness of its paved streets; but the stench, even in the best houses, was almost insupportable. The possibility of hermetically-sealed cesspools was therefore a fallacy. However much cesspools, or sewers were trapped, the foul gases would escape. No main sewer, or house-drain could be over-ventilated, but a great many were under-ventilated. After the first attempt to sewer the metropolis (from 1820 to 1840), and after the first sewers had been made, which only took the overflowings of putrid cesspits and cesspools (for then it was illegal to drain direct into the sewers), the first effects of this system was a considerable addition to epidemics and especially of

typhus fever. The sewers were unventilated, the foul gases fermented through the houses, and the inmates of the houses breathing those gases were afflicted with typhoid, or typhus fever, in some form or other. Thus it was that the ventilating of the metropolitan sewers was brought about; but even now, although they were pretty liberally ventilated, it was done in a clumsy and obnoxious manner. A shaft, carried from the crown of the sewer direct to the street, and opened by a grating upon the surface above, admitted into the atmosphere whatever gases were generated in the sewer below. The present system of ventilation was the source of two mischiefs: the gases were passed unmodified into the atmosphere, and the grates allowed stones and mud to fall through and form a barrier to the passage of the sewage below. It would be a simple thing to form a side chamber upon these vertical shafts, and to put an intermediate connection between the shaft and side chamber, placing the grating over such side chamber. The road grit would grind down into it, no doubt, but it would not obstruct the sewage. A wire tray, or basket filled with wood, or with bone charcoal, might be placed in the passage to the side chamber. The power of charcoal, in disinfecting or burning sewer gases, was in some degree as efficacious as the heat of a furnace. If that were done in the first place, the blocking of the invert by the grinding in of the mud would not take place, and, to a certain extent, the foul gases passing from below would be disinfected. But the true way to ventilate a system of sewerage for a great city like London, or Paris, was to break the system up into sections, to lay the plans out in such a manner as to be absolutely masters of the position, and ventilate effectually as arranged on plan. For instance, all the low-lying districts of London should be so ventilated, that there could be no possibility of sewage gases ascending to the higher parts of the city. If London were thus dealt with, the whole of the gases from the lower districts would be prevented rising to the higher parts of Hampstead, Highgate, &c. Where the sewers had a steep gradient, they ought not to be allowed to come down an even incline. All steep gradients in sewers, under any circumstances, ought to be broken at intervals by steps, for two reasons: in the first place, it was very destructive to sewers, if the gradient was greater than was required for the proper discharging power of the sewer, the wearing upon the sewer invert being greater than it ought to be subjected to. If the gradient were broken, the rapid flow of sewage would be checked; and the lower end of the sewer could be protected by a hanging flap, not covering the whole area, but leaving at the bottom of the sewer, space sufficient to discharge the ordinary flow of sewage; and above, ample means might be provided for ventilation, by running off the whole of the gases up to that point, and discharging

them there, that they should not be injurious. It was not necessary to discharge the gas at the particular point where it was brought to the surface. It was possible for the Engineer to make gas sewers, or conducts, to lead the gases safely to any point at which he wished to discharge them so as to do a minimum amount of injury, and if he could not sufficiently get rid of them by the use of charcoal as a disinfectant, they might be burnt through a furnace, or discharged through an elevated shaft.

The intercepting sewers in the metropolis had been devised, at present, to carry the whole of the sewage to outfalls at Barking on the north, and at Crossness on the south, and enormous reservoirs had been constructed at those points to receive the sewage and enable it, at certain states of the tide, to be discharged at the ebb of the flood. In his opinion that was a mistake. The flow of sewage was constant, and in the metropolis it was so enormous, that if tanks were used they must be large and costly works, in which the matter would collect, and although, if it was discharged daily, the matter itself would not perhaps putrefy, in bulk, yet the sediment that was left in those tanks, and the filth which become entangled and hung about the walls, would set up putridity, and the tanks would become foul abominations. If the money expended upon those tanks had been expended in continuing the outfalls to any given point below, equivalent to the same purpose of preventing the sewage coming back again by the incoming tide, it would have been much better spent.

With regard to the Parisian sewers, it had been stated that those sewers were made to take away surface water only, and not sewage; he was sorry to say, that that principle had been adopted by the French government in other cities and places: in Lyons, and Marseilles, for instance, the same system was carried out. Large sewers were constructed with subways, for the passage of carts, and railway trucks which received the refuse emptied out by hand-labour; that refuse, if the sewers had been constructed upon proper principles, would have been carried out by the action of the water flowing regularly through them. To show how perfectly this was done in sewers properly constructed, he would instance Birmingham, where the outlet sewers were egg shaped, or circular. Birmingham was, perhaps, about as difficult a town as any Engineer would wish to deal with, for there was not a mile of paved surface, the whole of the roads and streets being macadamized, and very few of the channels being paved. That part of England, too, was subject to violent summer floods; the tributary gradients of Birmingham were very steep; and grit was washed down into the sewers, until at the outlet tanks, in the lower part of the system, there were no less than 25,000 tons of gritty matter per annum, which had to be removed. This heavy matter had been regularly

washed through the sewers, showing that when sewers, made upon the egg-shape principle, were graduated to anything like their work, they would carry off anything that might pass into them, from the streets and drains.

Admiral BELCHER, in reference to what had fallen from Mr. Rawlinson, suggested that a large portion, if not the whole, of the noxious gases evolved from the sewers, might be burnt, by connecting the sewers with the street lamps and large factory chimneys.

Mr. W. HAYWOOD said, the subject of large sewers and small sewers, which was earnestly discussed before that Institution many years ago, had been again alluded to, but it had really nothing to do with the matter, although many persons thought it had. Rightly, or wrongly, there were, at the period when the intercepting sewers were first designed, a thousand miles of sewers in the metropolis, mostly of large size, and every house was draining into them, the whole of the water-closets in the metropolis were being discharged into the sewers, and the sewers all discharged into the Thames. The problem which had to be solved was, therefore, how to get rid of the nuisance incidental to that state of things, in the quickest and cheapest way, and there were four points to be determined, before a scheme for that object could be framed. The first was the outfall, and that was originally fixed by the late Mr. Frank Forster and himself, and had never been altered (he alluded to that on the northern side), although successive Engineers had considered the matter. The next was the prospective population over the extensive metropolitan area. After much consideration, this was fixed at 30,000 per square mile, and that number had, also, been subsequently adopted. Then came the question of the water supply which was to be given to this prospective population, and it was taken at 5 cubic feet per head per day. It had been frequently stated by professional men, that a larger consumption per head might be expected, but he thought the time would come when the water supply must be economised, and when 5 cubic feet would certainly be the maximum consumption of the metropolis. The point which was most difficult to determine was the amount of rainfall to be carried off. He believed that he fixed upon the exact amount which was decided on by Mr. Forster, viz., a quarter of an inch per twenty-four hours; and that was afterwards adopted by Mr. Bazalgette and himself. The soundness of these conclusions had been subsequently confirmed by men of the highest reputation, and were the basis of works that, no doubt, would perfectly effect that which was anticipated from them.

There was one point which he thought was deserving of discussion, and that was, whether the water-closet system was a right

one. This was one of the most important questions that had to be considered, inasmuch as upon the continuation, or not, of that system, it depended whether the most valuable manurial products of the whole country should be rendered valueless, or almost so, as they at present were, in the metropolis. He most sincerely hoped that this subject, in its relation to small towns yet undrained, would be well and carefully considered, because the necessities of London were not the necessities of smaller towns. In small towns it would be well to consider, whether it was desirable to adopt the water-closet system, and, as the consequence, to discharge its sewage into a river, or to adopt some other less wasteful system. If the town possessed ample garden-ground, ample room for ventilation, and for the construction of closets and other accommodation of that character, so as to cause no nuisance or offence, it might be possible to adopt some other system, and, if possible, it should be adopted.

With regard to the rainfall to be carried off by the intercepting sewers, which had been fixed by Mr. Forster and himself at a quarter of an inch, there was no allowance made for evaporation, or absorption; it assumed a uniform fall of rain in twenty-four hours, the total in that time amounting to a quarter of an inch, with a uniform discharge into the sewers during that period of the same quantity. But as rain seldom, or ever fell with regularity, and it never happened that the quantity which fell was delivered in its entirety into the sewers, a margin was actually allowed for a much larger rainfall. Those sewers which were to take the entire drainage of districts, as well as to act as intercepting sewers, were of course intended to carry off all the rain which might find its way into them, and were regulated, as to size, by a different formula; but, as he had before observed, under any conditions, the quantity of rain which fell was never entirely delivered into the sewers, not even on occasions of the greatest storms. This question had an important bearing upon the size of sewers generally, and though the main and intercepting sewers of the metropolis had been determined on as to size, yet it was important in regard to districts of, or adjacent to, the metropolis not yet built over, or drained; for with the rapid extension of London there would, before many years had passed, be some districts which would require main sewers. Now the observations of Mr. Bidder and Mr. Hawksley, in 1857, upon the Savoy Street sewer, showed that of a rainfall of 2·90 inches in twenty-six hours, only 64½ per cent. of the fall was delivered into the sewers, all the rest being either absorbed, or evaporated. In the Ratcliff Highway sewer they found, on the same occasion (which was an unusual rainfall, it having rained without ceasing, he believed, for twenty-six hours), that 52 per cent. of the total quantity only was discharged into the sewers. It so happened

that, without any co-operation with the gentlemen named, he was at the same time engaged in gauging the flow of the London Bridge sewer, which drained an area of 2,250 acres, partly urban, and partly suburban; it was necessary that this should be known, as the character of the surface much affected the quantity delivered into sewers in times of storm. Now, with the same rainfall, or rather a fall of 2·75 inches instead of 2·90 inches, being the amount recorded by Mr. Glaisher on the occasion alluded to, he found, that in the London Bridge sewer, 53 per cent. of the total quantity only ran off. On one occasion, in April, 1858, he had gaugings taken of the same sewer, when 0·24 of an inch of rain fell, in an hour and a half: he then found that 74 per cent. of the total quantity was run off, leaving 26 per cent. absorbed or evaporated. Of a rainstorm of 0·54 of an inch in five hours, in June, 1858, there was delivered into the Irongate sewer, which drained an area entirely paved and built over, as much as 94½ per cent. of the total rainfall, and that, of all the storm-gaugings he had made, was the greatest per centage of rainfall he ever knew to be discharged by a sewer. In August, 1858, with a rainfall of 0·48 inch in one hour and two-thirds of an hour, he found only 78 per cent. of the total quantity discharged into the Irongate sewer. There were, of course, many circumstances which would affect the quantity of water which would be discharged into sewers from rainfalls: no two cases would be alike. Storm-gaugings had been, he believed, but little taken by any one; in fact, it was a difficult matter to get them taken at any time, as they required men to be in readiness at any moment to make the observations, and competent assistants to see that the men did their duty. He had paid much attention to these points for many years: he had had the requisite staff in readiness, and he believed his observations were as accurate as it was possible to make them. It had been stated, that one-half of the whole daily discharge of the sewers of the metropolis took place in six hours, and that the hours of minimum discharge, at the west end, differed much as to time, from that of the east end of London, that being attributable to the difference in social habits. Now he believed there was no material difference whatever in the periods of greatest discharge of the sewers; and that, taking the outlets of all the main sewers of the metropolis, the maximum discharge took place nearly at the same time; certainly, upon the averages of some hours, it was so. In 1850, no gaugings existed that he was aware of, except those taken by Mr. Hawkins in 1844, which related only to some of the sewers in Westminster, and were not of a character to be then serviceable. Mr. Frank Forster and himself had no gaugings of the sewers to aid them, as they did not, in fact, exist. They found it indeed stated in one

of the Reports of the Board of Health, published about 1847, or 1848, upon the evidence of Mr. Phillips, that half the daily sewage was discharged in six hours, but the Blue Book referred to was remarkable for assertions and statements, and for the absence of that detail by which the correctness of the statements could be checked, and Mr. Frank Forster and himself applied for but could not obtain, either from Mr. Phillips, or Mr. Roe, or from anybody else, information which would aid them in this investigation, and he believed that, at that time, there were no reliable gaugings in existence. They therefore took some general observations, collated the opinions of the various officers and others consulted, and arrived at the conclusion, that in deciding upon the sizes of the sewers, the safest course was to take double the then existing water-supply. That, added to the quarter of an inch rainfall, was the quantity then provided for. In 1853, when he and Mr. Bazalgette were engaged together in perfecting the scheme for sewage interception for the north side of the Thames, the information on this subject was much more extensive than in 1851, but still no complete gaugings existed. He therefore, in that year, commenced an extensive series of gaugings of the discharges of sewers which drained 11 square miles, including some of the most densely-populated districts of the metropolis, as well as suburban districts. These gaugings were carried on, night and day, for months, and he deduced from them the fact, that the average discharge of the sewers in eight hours, was 49 per cent. of the whole daily discharge. Within one year, or two years afterwards, Messrs. Galton, Simpson, and Blackwell gauged all the sewers of the metropolis, and they ascertained, that almost exactly the same proportion was discharged during the eight hours, as he had proved to be the case in those sewers which he had gauged in 1853. The details of his own gaugings were published by him at the time, while those of the gentlemen he had named were embodied and published in their Report,[1] in which they also drew attention to the fact, that he (Mr. Haywood) was the first who had ever taken a complete series of gaugings, and that their gaugings were entirely corroborative of his results; and it might be taken as a positive fact that, as nearly as possible, one-half of the daily sewage of the metropolis was discharged between 9 A.M. and 5 P.M., or in eight hours, and that the social habits of those who lived at the west end of London, therefore, did not affect that point at all. That circumstance, however, did not vitiate the present scheme. Although that provided for half the sewage in six hours, it only gave a little

[1] *Vide* "Report upon the Main-Drainage of the Metropolis, by Messrs. Douglas Galton, James Simpson, and Thomas Blackwell."—Parliamentary Paper, August 3rd, 1857, No. 233, Sess. 2.

more room for any additional rainfall, and that was all; but as the Members of this Institution should have the facts, as nearly as possible, he ventured to lay these before them, and to give the references by which the correctness of his statements might be verified.

With regard to the ventilation of the sewers, the mode at present in use throughout the metropolis, and the country generally, was not designed by Mr. Roe, but by Mr. Richard Kelsey, in the year 1840, and the first gullies which were trapped were those in the City of London. He had no credit to claim in the matter; he merely referred to it to correct an error as to fact. He believed the London sewers were kept in fair condition at the present time. The sewers of Paris were ventilated entirely by the gullies; they had no central openings as in the metropolis, and he mentioned this, because he did not think that point was alluded to in the Paper on the Drainage of Paris. The temperature of the sewers was a point which bore upon that of their ventilation. He had ascertained that the mean temperature for the year, in the sewers of Paris, was 63° Fahr., while that of the sewers of London was about 55°; in the hottest months he never found the mean to exceed 62° Fahr. Notwithstanding that a large quantity of fœcal matter went into the Paris sewers at the present time, indeed far more than was usually thought to be the case, they were undoubtedly much less offensive than the sewers in London. This was a subject which, perhaps, could be more usefully discussed by medical men, or chemists than by Engineers; but he might mention that, having made observations with regard to the sewage of many countries of Europe, he found that the effluvium of the sewers was greatest amongst the northern nations. In England the effluvium was, he thought, worse than in any: he alluded in all cases to the internal atmospheres.

Some remarks had been made about the large size of the Parisian sewers. The Engineers of the Ponts et Chaussées, who had charge of the sewers of Paris, never recognised, in the slightest degree, the pipe system. They proceeded upon the assumption that it would be necessary, at some time or other, to have their sewers inspected, and for men to work in them; and having settled that point, they next determined to make the sewers large enough to enable men to work in them with some degree of comfort; and if the first point were conceded, he was not sure they were not right in the second. In an economical point of view, the difference between men working in sewers where they could not stand upright, and where they had good head-room, was very great indeed. In a sewer 4 feet, or 3 feet 6 inches high, a man could not do as much work in a day as he could in two hours, in a sewer 6 feet high. He was therefore inclined to think that

the Parisian Engineers, if they were right in the first assumption, were undoubtedly right in making the sewers of their actual size. He had often regretted, that the funds at his disposal would not allow him to make some of the sewers in the City of London of larger dimensions, mainly on account of the facilities of inspection, and of working in them.

Allusion had been made to the mode of cleansing the sewers of Paris. It was to be recollected, that throughout Paris, the largest portion of the street-sweepings went into the sewers; the contents of the gutters were always disposed of in that way. The detritus of the roads was not so heavy as that in London, owing to the difference in the material employed for the road surfaces; still it was a heavy material, and a large amount went into the sewers, and it was principally in the removal of that detritus, that the sewer-men were employed. It was to be remarked also that it was done at a great cost. He had ascertained, that about three men were required to every two miles of sewers, these men being entirely engaged in helping to keep that length of sewer clean; and the total cost for wages, superintendence, lighting, clothes, &c., he believed, was about £100 per mile per annum, while in London the whole cost of cleansing the sewers, including the expense of water for flushing, and the labour bestowed upon their interior, and also of keeping the gullies and ventilating-shafts in condition, which in the City, owing to the enormous traffic, was a work of considerable labour, and a heavy item of expense, was about £40 per mile per annum. But though the sewers in the City were kept clean, they were undoubtedly not in such a state in that respect as the sewers of Paris. It was impossible, without making a personal inspection, to conceive the extreme cleanliness of the sewers of Paris, not only of their inverts but of their entire internal surface.

Mr. F. J. Bramwell said, there was one point of great importance in connection with this system which had not yet been alluded to,—that was the pumping engines. Without the aid of those engines it would seem that two of the most important and densely-populated areas of the whole district could not have been drained as they had been, with the hope of delivering the sewage water at such a distance from London as that it should not return by the river so as to be a nuisance; and therefore the pumping operations must be regarded as a vital point of the system. He believed it was this which distinguished the sewage of London from that of every other large city in this, or in foreign countries. Twenty years ago, it would have been considered a most serious thing to attempt the application of steam power to the getting rid of so large an amount of water. The duty of these engines was stated to be, at Crossness, 20,000 cubic feet of water per minute,

and at Abbey Mills 16,000 cubic feet per minute, which was equal to a river 40 feet wide, 3 feet deep, and running at a velocity of 3 miles an hour—an enormous stream to raise and keep in motion by artificial means. He was glad that the gentlemen who advised upon these engines had recommended, that the rotative engine should be used instead of the Cornish. He thought, at the present day there was far less difficulty in coming to a proper decision on this point than was the case at the time this question was decided. No doubt, Cornish engines had been put up in London for lower lifts than these, and the results had been most disastrous; he was afraid to say how much duty was got out of them, but he believed it was not more than one-third of that which was guaranteed in these engines. He was surprised at the duty stated of 80,000,000 lbs., amounting to about $2\frac{1}{4}$ lbs. of coal per theoretical H.P. per hour, the theoretical H.P. in this case being, as he understood, calculated on the amount of water delivered, so that for the gross indicated H.P. the consumption of coal was only about 2 lbs. of coal per hour. The undertaking on the part of the contractors to fulfil this duty showed the great confidence they had in the design of the engines. There was, however, one matter which he should be glad to have explained—that was, as to the different relations between the work to be done, and the size of the engines at Deptford and at Crossness. At Deptford the lift was not quite 20 feet, at Crossness it might be as much as 36 feet. The cylinders of the two engines were of equal size, and the length of their stroke was equal. The pump strokes were half the length of those of the cylinder; but in the Deptford engine, where there was a low lift, the area of the pump-plungers was 49 circular feet, or 3 to 1 as compared with the 16 circular feet of the piston; while in the Crossness engine, with a high lift, the areas of the four plungers were 81 feet compared with the 16 feet; that was five times as great with a lift of nearly double. The result of this large area of pump-plunger, combined with high lift, was to put on the Crossness engine a load that required an average pressure of 30 lbs. per square inch all through the stroke of the piston to meet it; but to realise that average pressure all through the stroke of the piston, was imposing on the engines a very high load. The Paper stated that the plungers were made in sets to be disconnected and worked in ratios of 1, 2, and 3, but he did not gather that it followed, that when united to raise the greatest amount of sewage they were wanted to raise, they would be always pumping at the lowest lift, or that they might not have to use the greatest amount of pumping capacity combined with the greatest lift. It appeared from the Paper, and in the absence of the explanation that no doubt could be given, that at Deptford the engines were

not sufficiently loaded, while at Crossness the load might often be a heavy one. He noticed in the Paper the statement that the foundation of the boiler-house was used as a tank for cooling the injection-water. It seemed that there was in this case little additional cost to make those tanks; for some chamber must have been made in taking the foundations deep enough to support the building above, and it was therefore comparatively a matter of indifference on the score of expense, whether afterwards the space was used to store injection-water or not; but if this had not been so, it appeared to him, looking at the extensive use of surface condensers, either totally immersed, or of evaporative condensers (which also worked well), it was not expedient to go to a large outlay for cooling injection-water, when those well-known means were at hand as a substitute, and were also valuable as giving pure feed-water. The valves at Crossness and at Deptford were stated to be leather valves. He thought it would be found, that the leather would not answer, but that india-rubber facing would be better, as it was sufficiently elastic to reject the particles of gravel; and that circumstance might make all the difference between the proper, and the improper working of these engines. It appeared to him that the plunger-pump adopted, arranged so that half the work was done by the suction and half by the lift, was the best that could be devised for equalising the strains upon the engine. He should have been tempted, if he had had the advising upon the designs of the engine, to have adopted an excess of metal in the beams, so as to act directly in equalising the irregular strain due to working steam expansively. The beams, however, were of the ordinary size, and the means of equalizing the effect of expansion were put into the fly-wheels. But if that were done, viz., the putting extra matter into the fly-wheel to equalize expansion, he should have been tempted to have adopted the blast-engine plan of putting the fly-wheel at the cylinder end. These were the only observations that occurred to him with respect to the engines, and he had no doubt the Author would give a satisfactory explanation as to the apparent discrepancy of the load, to which he had referred.

It had been stated that in Paris, as a rule, the sewers were used, not for the carrying away of solid refuse matters from the houses, but only for liquid sewage. It had also been urged, that the legitimate purpose of sewers was to take the matters from the houses, and that they should have nothing to do with surface waters. Again, it had been said, that in inland country towns, such a system might be correct; while in London there were sewers not only taking the refuse of the houses, but also a great part of the storm-waters. All these three plans had their advocates, and no positive decision had been come to, as to which was the best. If the first

view were correct, then the surface water ought not to be considered at all, and only the sewage from the houses should be dealt with; if the second system were right, sewers for houses must be abandoned. Now, it only required to put these two theories together, and it would result in the entire abolition of sewers. The difficulty in which they were left seemed to be this, and he stated it thus early, in order that those who were competent, might explain the real office which sewers were required to fulfil.

Mr. HAWKSHAW, Past-President, said that, as regarded the size of sewers, and their being sufficiently large for a man to enter them, no doubt it was a disagreeable duty to be obliged to send men into sewers, but at present there was no means of obviating that necessity. It had been stated, that the plan of sewage was so regular and so uniform, that all Engineers had to do, was properly to apportion the size and the gradient of the sewers to the quantity of sewage to be discharged, and that the sewage would then run on in a perpetual stream, and that the sewers would in consequence never require any artificial cleansing. These views appeared to him, in many cases, to be inapplicable; in the case of towns in flat districts, how were gradients everywhere to be obtained precisely fitted to this assumed regular and uniform flow? The assumption that the flow through a sewer was uniform was fallacious; he would say that he knew of nothing, in his experience, that was less uniform. The fact was, that the flow along sewers must be irregular. Dealing only with that portion of sewage which came from the houses, cesspits, and water-closets, even that could not be so regular as seemed to be required to carry out the theory he referred to, but when rainfall was admitted into the sewers, the whole assumption of uniform flow immediately vanished. In England there were sometimes months of dry weather, and months of rainy weather, and it was impossible therefore to devise sewers of such areas and gradients as would, at all times, be exactly proportioned to the amount of fluid which would pass down them. He was a Member of the last Royal Commission of Sewers, and he remembered, that a portion of a district in London had previously been given over to certain gentlemen, who held the views upon which he was commenting, and who were authorised to drain it after their own fashion. Those gentlemen were allowed to carry out their plan of back drainage and front drainage, &c., and he believed they did so with great skill, and as ably as it was possible to carry out the system for which they contended; but the result was, that five years, or six years afterwards, the drains were obstructed and stopped; and, if he recollected rightly, the end of it was, that the whole had to be dug out. The occasion of its failure was obvious—there was no such uniform flow of sewage as the system required. It was impossible to accurately apportion sewers both to a dry, and to a wet state

of matter. But, besides this, even if there was a uniform flow, in many districts and towns, the ground was too flat to admit of gradients suitable to such a theory; at all events, without pumping to a much larger extent than many small places could afford.

With regard to the great work of the metropolitan drainage which had been brought before the Institution, and which, so far, had been most successfully carried out, he knew something of it from having been a Member of the last Royal Commission, which had to consider the scheme, before it went into the hands of the Metropolitan Board of Works. In common with the other gentlemen who were members of that Commission, he indorsed the proposed plan which had been elaborated by previous Commissioners, and which was, so far as they could then tell, the best system for the drainage of the metropolis that could be devised. Looking to the future, however, he had, on one point, some misgiving in which he hoped he was mistaken, but it was a matter which was worth consideration. It affected nothing that had been done, but merely raised a question, as to whether something more was not required to be added to it. The system embraced many miles of underground drainage. These sewers could not be, as he had endeavoured to point out, so apportioned as to size, and so graduated as to inclination, as at all seasons to fit the flow of sewage and of rain water. It was possible in this metropolis, to have occasionally, summers of unusual drought, and to be for months without rain, and the question was whether on such occasions, unless the sewers were flushed, serious epidemics might not result from this new system of sewers. He was not now broaching a new opinion, for the last act which he performed when a member of the Commission of 1854 was to write to Mr. Jebb, who was then the Chairman of the Commission, to explain the mischief which might result unless ample powers of flushing the sewers were provided. He believed, wet summers would be healthy, but he feared dry summers would be sickly, unless the sewers were capable of being thoroughly flushed. The suggestion he made at that time was, that means should be provided for forcing water into reservoirs at the upper extremities of the large intercepting sewers, to be used in dry summers, for flushing the sewers, about once a week, but the oftener the better.

Having said thus much on this branch of the subject, he had to add a few words with regard to the past history of the scheme. It had occupied the attention of a great number of gentlemen, for a long period of time, and the history of it should be correctly given. He would go as little as possible into the question of individual claims, because that would most likely lead to a tiresome discussion. He thought justice should be done to Mr. Frank Forster, to Mr. M'Clean (President Inst. C.E.), and to others who had

devoted much time to the subject. But, without going into the question as it regarded other individuals, he would suggest that the Report which was laid before the Metropolitan Commission of Sewers on the 15th of March, 1850, and which was signed by Sir John Burgoyne, Captain Vetch, Mr. Rendel, Captain Harness, and Mr. Robert Stephenson, together with a Report, written by Mr. Frank Forster on the 1st August, 1850, and one by the same gentleman on the 30th January, 1851, should be printed in the Proceedings.[1] Those three reports would sufficiently show what had been done, previous to the drainage of London being intrusted to the Metropolitan Board of Works.

Mr. Edwin Chadwick, C. B., said that, in his view, most of the early historical matter might have been omitted from Mr. Bazalgette's Paper, as of no engineering consequence, whilst much of recent history (immediately preceding the appointment of the Consolidated Metropolitan Sewers Commission, of which Mr. Hawkshaw had been a prominent member) ought to have been included, as of importance for engineering science and for the benefit of young Engineers. Mr. Chadwick's examinations had led him to propound as an administrative principle, that the proper chief attributes of local administrative bodies, were works—works of water supply, of house drainage, for the removal of waste and foul water, of subsoil drainage, for the relief of surcharged sites, of garden and uncovered areas, for the formation of roads, for their maintenance and cleansing, and that all these works should be comprised under one local administrative body, and that body a competent and really responsible one. And, further, that the area of the administrative jurisdiction should be defined by the Engineer, and its foundation being drainage works, that to be efficient and economical it should comprise the whole of the natural drainage area, from the line of watershed at the hill top, to the valley bottom, or the outfall at the river. Thus, for example, the drainage area, and administrative jurisdiction proper for the metropolis would comprise the hill tops of Hampstead and Highgate, down to the Thames, and the area up to any river divisions east and west, which might comprehend reasonably connected portions of the covered and uncovered suburban connected areas. As a matter of history, it should have been recorded, that the principle thus stated, had been partially applied in the case of the metropolis, by the consolidation of seven conflicting and capricious jurisdictions into one;—with the exception of the jurisdiction of the corporation of the City of London, of one square mile of covered area, which in despite of engineering as well as of administrative principle, was allowed to remain independent and obstructive in the

[1] These three Reports will be found in the Appendix to this Volume, p. 513.

midst of some twenty square miles of metropolitan covered area. The southern part of the metropolis, as divided by the Thames, might, in strict engineering principle, have been dealt with separately, and have been placed under a separate administrative authority; but he had proposed that the south side should be included in the same jurisdiction, on economic grounds,—to save the unnecessary expense of separate establishments, of separate water supplies, and on other grounds on which uniformity was conducive to economical administration. The historical statement should have stated the fact, on engineering as well as on administrative principles, that by means of this consolidation, a general survey of the whole area had been obtained, which had served as the foundation of the Main Drainage Works in question. As the public paid for Royal Engineers, who had in peace little to do, he thought they might as well be employed in doing such a work, and it would be acknowledged that they had done it well. There was another point to be noted, in connection with this survey, as new in town drainage works on such a scale. His own investigations in sanitary matters, had led him to the conclusion, that all such works, to deserve to be called systematic and complete, must comprehend the means of the constant removal of all refuse, from the house or from the water-closet to the farthest outfall; that the main trunk lines must be adjusted to amended and self-cleansing branch sewers, and that the amended self-cleansing branch sewers must be adjusted to amended self-cleansing house drains,—which, as being self-cleansing without storm or rain water, or the need of flushing, were as a system, a new invention. The general survey of the whole of the drainage area had been accomplished on a scale to include the drainage of every house, or yard, or stable. As connected with the foundation laid for complete town drainage work by a survey, there was another point, which should be mentioned for the completion of the historical matter. Of the several old drainage jurisdictions, it might be supposed that by a sort of subdivision of labour, they had the most complete knowledge and records of the existing works. But their knowledge was most imperfect, and except of large and recently-constructed works, there was really nothing deserving the name of record. To provide for any systematic amended drainage, it was necessary to ascertain what sewers there were, and what was their condition. Besides the great surface survey, therefore, a general subterranean survey of all the existing sewers that could be found was undertaken, and completed, as should be done in all cases of old cities. In some fifteen hundred miles of streets, there was on this subterranean survey found to be some thousand miles of sewers of deposit,—sewers which detained, to be cleansed at an expense of upwards of twenty thousand pounds per annum, what a

good system of sewers, mostly tubular, removed constantly before it could enter into noxious stages of decomposition. Judging from the smells in the streets and the price paid for cleansing, this length of sewers and their contents had been little disturbed by any new outfalls; or were, he apprehended, likely to be. The proceedings taken on another topic should be noticed, as of great sanitary as well as of engineering and economical importance. Finding the vast extent of noxious evaporation from the old brick house drains, as well as from such sewers of deposit, which were really only extended cesspools, he could not but ask—whether this was a normal condition of things and a final result of all engineering art; and he called for the rules on which such constructions were regulated, when he found that the hydraulic formulæ in use even among Engineers of the greatest eminence, who had had the direction of the largest expenditure in such works of town-drainage, in which it appeared they followed the empirical practice of architects, were widely contradictory and erroneous as to the requirements of pipes for the discharge of water. The old formulæ were founded on experiments mostly on a small scale, and applicable only to very different circumstances, and when applied to common drainage works, they presented differences of more than one-third even in the discharge through six-inch pipes; and observations preparatory to actual experiments were made, which showed that the differences between the fact and the common practice, as well as the common formulæ, increased in a still greater ratio with the larger discharges of water. The only way out of the difficulty in obtaining sanitary as well as economical results was to promote new trial works, which was done. In respect to town drainage, the practice of architects, and of some engineers who followed them, was to enlarge the area of any main pipe in the proportion of the sectional area of each junction into it: whereas it was found by the trial works that the addition of eight junctions, each of 3 inches diameter, into a main line of pipe of only 4 inches diameter, so increased the velocity of the stream, that there was no increase of its sectional area required. It was a practice in town drainage, and defended, too, by professional men, to make junctions of streams at right angles, and it was now the common practice to form the junctions of land-drains at right angles and with projecting pieces, so as positively to impede the flow. On a large scale it was found that when equal quantities of water were running direct at a rate of 90 seconds, with a turn at right angles, the discharge was only effected in 140 seconds, whilst with a turn or junction with a gentle curve the discharge was effected in 100 seconds. He would cite one illustration of a trial work in a sewer of the class of the vast extent of sewers of deposit to which he had adverted. In this sewer which had a flat segmental bottom 3 feet

wide, a sectional area of 15 feet, and an average fall of 1 in 118, the deposit from the 1,200 houses regularly accumulated at the rate of 6,000 cubic feet per month. But a pipe of 15 inches diameter placed along the bottom of this sewer, with a somewhat less inclination (1 in 153) kept it perfectly clear of deposit. The average flow, without rainfall, was about fifty-one gallons per house, per diem; the absolute sewerage, apart from rainwater, from all the 1,200 houses would have passed through a 5-inch pipe (of the relative size of the smaller one placed along the bottom of the brick sewer) within the 15-inch tubular pipe, or not one-third the area of the minimum-sized drain which had, up to the time of the investigation and upon the advice of professors of architecture, been declared and enacted in the Metropolitan Building Act to be necessary for a single house; namely, one of not less than 9 inches in diameter.

Since he had promoted the use of pipe sewers, he was told that upwards of twelve thousand miles of them had been manufactured and sold at Lambeth alone. They were often made inexactly, and laid ignorantly, and badly jointed, so as to let out the fluid, and like the old sewers detain the matter which it was the object to discharge; but on the whole they were a success. It would not be disputed that it would yet be important to have the results of the working of the various sizes of the channels, competently and impartially examined for the future guidance of young Engineers in this important branch of engineering science.

One important test of a complete system of town drainage was the condition of the sewage at the outfall. He had been in sewers and examined the chief outfall sewers of the metropolis, and other large cities, when it struck him, as remarkable, that neither in the branches nor in the mains could he discover a bit of paper, nor any fæces in form. He had asked officers and men engaged in them and their observation was similar. How was this, it might naturally be asked? The answer was that the sewage was either the overflow of cess-pits, or that the matter was detained in the old brick drains of deposit, or in the sewers of deposit, until it was disintegrated by decomposition, when the matter was discharged in this disintegrated state, or by occasional storms. When the new system of tubular house drains and pipe sewers in a town was completed, they were surprised to see 'coprolites' discharged in form, and masses of paper which might be read. At Salisbury, where the new pipe sewerage discharged, fresh upon all water meadows beneath the town, the fertility of which was vastly increased thereby, the farmers, in grateful acknowledgment of the value derived therefrom, were wont to call the pieces of paper which bestrewed their fields 'bank notes.' On the old system, the drainage of that city was pronounced to be impracticable, but on

the new system well adjusted main-pipe sewers would be found to be self-cleansing with such falls as 1 in 1,000, and notwithstanding all that had been said, it would on proper examination appear, that the construction of sewers of deposit, or of a size for men to enter and cleanse them, must be classed as things of the past, and the bad. One method of testing the action of a complete system of town drainage works, was to go to the water-closets of the upper part of a town, and discharge from thence substances such as might be recognised, pieces of turnip were very convenient, and time their arrival at the outfall. If these pieces were detained, or were comparatively slow in their arrival, the work was bungled somewhere and incomplete. When the new works of a town were completed, not only for the discharge of the sewage of a town, but for its proper application to agricultural production, it might be immediately taken up by engine-power, and be distributed over distant fields. It was proved that, as a rule, the sewage of the largest city, of the metropolis itself, might be thus deposited on the day of its production; in small towns, within less than half a day. He might mention, as an illustration of the rapidity of its application, that on one occasion he took some French commissioners to see the works at Watford. A drove of bullocks preceded them to the slaughter-house. The visitors paid their respects to the Earl of Essex, and then went to see the outfall of the town sewerage, which was reddened with the blood from the slaughter of those same bullocks; which blood was being taken up by the engine, and might have been distributed over the fields, possibly whilst it was warm. Now, it was to be observed, that the waste refuse of towns, which a complete system of exterior, as well as the new interior works, enabled to be so quickly deposited on the land, was, with proper preparation of the land, and the proper adaptation of the quantities of manure to its absorptive power—deposited not in mechanical or chemical suspension, but in immediate chemical combination with the soil. At the outset of his investigations, Mr. Chadwick had had some correspondence on this topic with Professor Liebig, who decidedly discountenanced any application of the refuse of towns, in a liquefied form, to the land; and alleged that it would in that form be washed out by every shower of rain. He proposed a patent solid manure on that hypothesis. The patent solid manure, like the precipitants and solidified manures, on which money had been spent, had failed. The professor could not but recognize the proofs afforded by empirical trial works, as well as by carefully conducted chemical experiments, of the absorptive power of soils; and that manures distributed in the liquefied form were retained in the soil in fast combination, until they were taken out by vegetation. Hence they might be distributed over fallows, as well as by repeated dressings over land with growing

crops. The experience of Rugby had shown that it might, by proper agricultural management, be in constant distribution every day in the year. This was a point of engineering importance, as it showed that large storage reservoirs of sewage, so objectionable in a sanitary point of view, were unnecessary. The best storage reservoir, the most perfect deodoriser, and the cheapest, was the soil itself. As dependent on the due observation of trial works on the sizes of pipes, to effect the self-cleansing and quick discharge of sewage from houses as well as from streets, it had been proved that the sewage was obtainable by good works in an entirely new condition; that was fresh, instead of putrid. Along the streets, and at the outfalls of well-conducted sewerage works, there were now no foul smells, that was to say, no smell of decomposition, for decomposition would not take place within the short time of the discharge. It had been ascertained that with fresh sewage in ordinary weather, active decomposition began only in about four days; but with proper and complete works external as well as internal, all fæcal matter should be on the land within one day. Now, all decomposition was waste of manure.

In respect to stable manure, it was proved that when it was applied fresh it was one-third more powerful than when it was old, and so it was with all town manures. The effect of the new conditions, brought about by improved works in discharging sewage fresh instead of putrid, was shown in rivers; the old putrid sewage killed fish; the fresh sewage fed them. At Carlisle, which was pipe-drained, it was alleged that the fish had increased in quantity and had been greatly improved in quality. At Ely, which was pipe-drained, the best fish was found at the sewer outfall. At Salisbury, which was also pipe-drained, enormous trout had been caught at the sewer mouth; but although the Engineer might, pending the formation of new works, throw the fresh sewage into the river with impunity, the matter discharged from the London sewers was calculated to be about a year old, and in a state of putrefaction. But fresh sewage was too valuable to be thrown into the river to feed fish, and should be on the fields to feed men. A poetical French writer, Victor Hugo, had said upon this subject: "These heaps of ordure in the corners of the streets—these cart-loads of manure which go jolting along the streets at night—those horrible tubs of liquid—the pestilential flood concealed beneath the pavement—do you know what it all is? It is the meadow in flower—the green herb—the wild thyme and clover—it is the abundance of game—it is the flocks of sheep and herds of cattle—it is the contented lowing of oxen in the evening—it is the scented hay and golden corn—it is the bread upon our table—it is the rich blood in our veins—it is health—it is enjoyment—it is life: so it is ordained by that mysterious creation, which is transforma-

tion on earth and transfiguration in heaven. Give all this to the great crucible, and receive back abundance. The nutrition of plants is the food of man." This poetical description was more properly applied to fresh sewage than to putrid. Of the matter retained in the cesspools of Paris, as well as of London, the poet might be asked if he knew what it was. It was dysentery, diarrhœa, ravaging typhus, measles, miasmatic disease—the consequence of insanitary architecture, mal-administration, and bad engineering. Connected with the new system of town drainage works and the application of the sewage from them to production, there were important points to be observed, as respects interior arrangements not to occasion the unnecessary dilution of the sewage with pure water. Schemes for the separation of the rain water from town sewage has been objected to; but Mr. Chadwick differed from those who would exclude from the sewers roof-water from houses. He was for admitting such water, and also for admitting the water from paved surfaces, such as streets, mews, courts, alleys, and paved squares; for he had found reason to believe that such water —the surface washings of towns—commonly contained more manure (except at the end of heavy storms) than was delivered from within the houses. One load of stable dung was taken up daily from the surface cleansing of every quarter of a mile of such traffic as Regent Street. Then there was the soot on roofs, and the dung of birds and animals, all of which was frequently stronger manure than the sewage of houses delivered in dry weather. But the subsoil water proper—that surplus water which was obtained through permeable tile drains, from surfaces of gardens, open, unpaved squares, common and meadow land—ought not to be mixed up with common sewage, but ought to be sent to the river, or otherwise utilized. He had proposed that the subsoil water of the fields, and all the uncovered suburban areas, up to the hilltops of Hampstead and Highgate, should be utilized, amongst other things, for fountains at the lower levels, or for keeping fresh any ornamental waters which it might be expedient to continue; and so with the surface water of parks and open commons, a great deal of which water was eligible even for domestic use. Near the metropolis, and such cities, the subsoil drainage for public roads, byeways, and footpaths would yield far more water than was commonly supposed. It was a serious error to waste such water in the common sewers. It perplexed the application of the sewage, by the enormous and extremely variable extent of the dilution. And so with respect to the waste of water from the interior of houses in the water-closets as carelessly constructed, acted sometimes with half a gallon and sometimes with two gallons or more of water. By the information he had obtained by gauging the old sewers on the days of water supply, as compared with the run on other days

in dry weather on the intermittent system, it was proved that full three-fifths of all the pipe-water delivered in the metropolis was delivered in waste. These various conditions were often overlooked by chemists, who spoke of sewage as of a positive quantity, some asserting that sewage was absolutely of no value by the extent of dilution, never considering the dilution as waste, and brought about by a bad system. On the principle he had advocated, of cutting off all house sewage or drainage from brooks or natural streams, it was with such limitations, or extensions, that the axiom might be put forward, of "the rainfall to the river, the sewage to the land." In respect to outfalls, which were properly not the first but the last portion of works to be considered in such a system as the metropolitan works, he was of opinion that it was a mistake to send all the sewage of a city in one direction. He proposed to pump some of it back, as from Westminster, in the direction of the western market gardens and other cultivated lands. If it paid to carry up solid manure for such high lands as Hampstead and Highgate, it would pay for pumping up liquid manure for distribution; but the public mind on the subject of the application of sewage was not sufficiently advanced for him to press that principle. He had therefore yielded to the proposal of having intercepting sewers of the right sizes, the plans of which were on much the same lines, as far as he recollected, as those on the plan now before them, only they were much less costly, whether properly so might be determined by impartial observation. But it was a great misconception to suppose, that the sanitary condition of the metropolis was largely or most affected by the discharge even of putrid sewage into the river. It had been proved during the cholera, that the population who lived in houses immediately opening upon the river, and, indeed, living on the river itself, were less affected by miasmatic diseases than those living in the interior of the city. Dr. Macwilliam, the medical inspector of the Board of Customs, had proved, in respect to the Custom House officers living on board ships in the river during an epidemic period, that they had lost only two, and those two from diseases which there was reason to believe they had contracted whilst on shore. It was proved in respect to house drainage works and the removal of cesspools, that the type of health had improved house by house as the works were carried on, whilst he apprehended it would be seen with respect to these main drainage outfalls as now constructed, without due adaptation, as he considered, to interior works, would have very little effect in the reduction of the mass of preventible diseases in the metropolis. On the whole, he would advance, as axioms, that all smells of decomposing matter in towns, and all smells from sewers or house drains, denoted ignorant engineering, waste of money, of manure, and, moreover, of life. The

general effect of complete drainage works in the towns which he had named, where all cesspools had been abolished—though they were not always done in the most complete manner—had been to reduce the rate of sickness and death fully one-third. When corporation surveyors and others talked of "a judicious return to cesspools," they should begin by reintroducing them in their own dressing-rooms, or within their own suburban houses. In his view, in an assembly of Engineers, such a remark was, as a matter of art, like talking of giving up railways, and returning to the judicious use of broad-wheeled wagons, or of wheelbarrows.

Mr. PHIPPS said that, whilst expressing his high appreciation of the excellence of the works described, he thought that where so large a portion of the present plan depended upon the pumping power of the steam-engine, the name of his friend, Mr. Thomas Wicksteed (M. Inst. C.E.), might be appropriately mentioned. He was the first to propose steam pumping, for the permanent drainage of large towns, where the surface was too low to admit of drainage by gravitation. As early as 1841 Mr. Wicksteed proposed to drain the City of Berlin by means of steam power.

In the years 1845-46 and 1849, he proposed plans for the drainage of the metropolis, by means of a deep underground sewer, commencing in the earlier project, at the Ranelagh Sewer, Chelsea, in the other two, at Northumberland Street, Strand, and all terminating at Barking-creek, whence the sewage was to be deodorized and pumped into reservoirs to the level of high water; the nitrogenous matter and salts being precipitated by means of lime, which it was expected, from the opinions of trustworthy chemists, would yield a valuable manure. The sewage-water, now rendered limpid, was then (as at present) to be discharged into the Thames at, or about the time of high water. The plans for the above schemes were duly deposited for application for Parliamentary powers, but owing to the state of the money market at that period of depression, the necessary sum to comply with standing orders, could not be obtained. The estimate for the first of the above plans was £1,500,000, which, however, included the drainage of the south side of the river, by an outfall at the Greenwich Marshes. The last plan (of 1849) was for the north side only, and was estimated to cost £600,000. The sewer in that case was to be circular; at the lower end at Barking up to the London Bridge sewer, it was to have been 10 feet in diameter with a fall of 2 feet 3 inches per mile, and thence westwards 8 feet in diameter with a fall of 2 feet $9\frac{3}{4}$ inches per mile, being calculated, when full, to deliver 20 million cubic feet every 24 hours. At Barking, the whole was to be raised by pumping to a height of 58 feet 6 inches. Subsequently, in 1855, the sewage of the town of Leicester, under Mr. Wicksteed's plan, was lifted by steam pumping, for

the purpose of being deodorized and clarified, which it continued to be up to the present time; by a recent statement, the quantity of sewage was 21 million gallons per week, raised 24 feet high.

With regard to Mr. Wicksteed's plans of 1845-9, he thought there was quite sufficient resemblance to the present plan, to justify the conclusion that much valuable information was derived from the facts and figures accompanying them, and it was worthy of notice, how long before Mr. Frank Forster's well-known float experiments, Mr. Wicksteed had fixed upon Barking, as the best point for the outfall.

Mr. Bateman said he should be sorry that the dogmas advanced by Mr. Chadwick should pass without contradiction. The merest tyro in hydraulics would know that high velocities in drains meant great inclinations, and when Mr. Chadwick talked about eight 3-inch pipes forcing their full contents into one 4-inch pipe, and of velocities so high that a man must run to see that emerge at the outfall which he had deposited at some inner point, the fall must have been immense. Such a thing might possibly happen in mountainous districts, where one part of a town was hundreds of feet above the other; there, such magical performances might be attained, but what was to be done with many parts of London, such as Southwark, which was on a dead level? There, other measures must be adopted; with lower falls, there must be larger sewers, and larger sectional areas, for such a quantity of water could not be carried off in small pipes with a small fall. No Engineer would venture to enunciate these elementary truths in the Institution, if it were not for the positive manner in which Mr. Chadwick had spoken. He merely mentioned this for the purpose of telling that gentleman that his enthusiasm and his love of the subject had carried him away, for he had stated what everybody at all acquainted with the subject knew to be diametrically opposed to the facts of the case. He thought that Mr. Chadwick's dogmas were mischievous and dangerous, and with the best possible feeling towards him, he would say that he believed he could collect evidence for the administration of public affairs, and report on what other people had done better than he could carry out systems of drainage.

Mr. G. W. Hemans remarked, that it was impossible to have heard these two Papers upon the drainage of London and of Paris, without perceiving at once, the great superiority and the more complete results, which had been derived in the drainage of London. He had visited the works in Paris, which were magnificent and executed in costly style, as also, in some respects with the highest engineering skill: at the same time he confessed his astonishment at the comparatively small results which had been obtained from that undertaking; and those who

had not visited Paris, having heard these Papers, must regard with astonishment the fact that, after all the outlay that had been incurred, the solid sewage matters of Paris were not removed by the drains, but were carted away, while the deposit in the sewers was so great, as to require an outlay of £30,000 a year to keep them clean. The results of the London drainage were infinitely superior when compared with those of the Paris system. He could not forbear alluding to the opinion that, under this great Main Drainage system, the effects of a season of long drought might be more injurious than under the previous state of things. He thought Mr. Bazalgette was the proper person to reply to that point, but in his belief, it would be found, that the main drains of London were entirely free from dependence upon the rainfall for the flushing. If the present supply of water per head of the population were delivered into London, that supply would be quite sufficient to make all the sewers of London self-cleansing, and to prevent any dangerous results to the public health. He said this with all deference, but he believed and hoped, that there was no sufficient foundation for the alarming opinion expressed on this subject. He thought there was reason for congratulation, on the results of this great system of sewerage of London, and one of the points in which it was most successful was, that the whole of the sewage, north and south, was concentrated at two distinct points, so that it could be handed over to other parties, for the purposes of utilisation. The redistribution and utilisation of the sewage formed a natural consequence of the main drainage.

Mr. John Grant having superintended the construction of the southern portion of this important system of drainage, begged to offer a few remarks. With respect to the anticipation, that under certain circumstances, the sewers might become so charged with deposit, that an epidemic might result in consequence, he could state that such a contingency had in this scheme been carefully guarded against. They had the means at twenty, or more places on the Thames of letting in fresh water, and so thoroughly could these sewers be flushed, that it was impossible that either soft deposit, or hard material, could lodge in them. A stream could be sent through the sewers from Putney to Crossness sufficient to carry with it anything that could get into the sewer; a similar arrangement was made for the north side. In the low-level sewers water from the Thames and certain of its tributaries, was thus used. In the case of the high-level sewers, the water could be accumulated behind dams at numerous points, and be used for flushing if necessary. The Falcon, the Effra, and the Ravensbourne streams on the south side, and other rivers on the north, could in this way be let into the high-level sewers, for cleansing

purposes. The reservoir for condensing the feed-water was constructed under the boiler-house, because the ground upon which the Crossness works were built had to be excavated for foundations to a depth of 25 feet below the surface. If that space had not been used as a reservoir, the excavation must have been filled in with concrete, or other material. The plan adopted was the most economical as a foundation, and was made to subserve the important purpose of holding the water required for the engines and boilers.

With regard to the discrepancy between the steam power at Crossness and at Deptford, he would remark that at the latter place there was an almost uniform lift, varying only from 18 feet to 22 feet; whereas at Crossness, which was the lower end, there was a lift varying from 10 feet to 31 feet 6 inches. Moreover, the minimum quantity of water to be dealt with at Crossness was, in comparison with the maximum, as 1 to 14; the minimum being 1,330 cubic feet per minute, and the maximum 19,000 cubic feet; but there never, by any possibility, could be the extreme lift with the maximum quantity of water to which Mr. Bramwell had referred. To bring 19,000 cubic feet of sewage per minute it must rise to a level of 11 feet 6 inches above the invert, which reduced the lift. These extreme variations in the lift, and in the quantities to be lifted, accounted for the peculiarity in the arrangements of the pumps at Crossness. At Deptford they were simply single plungers, 7 feet diameter, working in a 9-feet barrel. At Crossness the pumps had 12-feet barrels, and in each pump there were four plungers 4 feet 6 inches diameter; two plungers having a stroke of 4 feet 6 inches, and two having a stroke of 2 feet 3 inches. When they had a minimum quantity of water to deal with, they had simply to disengage the two pairs of outer plungers of one pump, and to work with one-third the power of one engine. When they had the maximum quantity to lift, the whole of the plungers of the four engines, 32 in number, were worked, and were capable of lifting the 19,000 cubic feet per minute to the level of high water, and at this rate the reservoir could be filled in four hours. An additional reason for the apparent discrepancy of pumping power at Crossness, and at Deptford was also furnished by the fact, that at Deptford there was no reservoir; moreover, to the west of Greenwich, the sewers rose with more rapid inclinations and were of smaller capacity, and in time of flood it was necessary to keep pumping into the outfall sewer, and thence into the reservoir at Crossness. If the water was allowed to rise at Greenwich to a level of about 14 feet above the invert, it began to affect some of the lower basements of the warehouses and dwellings in Bermondsey, Rotherhithe, and the lower parts of Southwark. On the other hand, they had at Crossness a reservoir capable of

holding double the present discharge from the sewers during each tide, and they had in addition an equal capacity in the sewer itself from Greenwich to the reservoir. In other words, they could store in that sewer $4\frac{1}{4}$ millions of cubic feet in addition to the 4 millions of cubic feet that could be stored in the reservoir at Crossness. There was storage-room, therefore, for a quantity of sewage equivalent to four times the amount they would get in one tide.

There was another point of interest to which he would refer in connection with the reservoir at Crossness; namely, the character of the invert which they were compelled to adopt on account of the unfavourable nature of the ground. As he had stated, the foundations of the walls and piers were 25 feet below the surface. Had they been taken to a less depth than that they would not have been safe. To get over the difficulty in the least expensive way, longitudinal arches were carried from north to south in the line of the piers, and between them, were built convex arches, and upon these again were placed the inverted arches, the object of the latter being to facilitate the process of flushing away the deposit which might accumulate from time to time. In speaking of the reservoirs and sewers, reference had been made to the subject of ventilation; that was a matter requiring great consideration and opening a wide field for discussion. He wished, however, to say, that this feature had been by no means neglected. In the course of the last few years, in fact before these works were commenced, they had tried almost every scheme of ventilation that had been suggested. They had ventilated the sewers by means of the steam jet, and into chimneys. At Deptford the sewers and at Crossness the reservoir were ventilated through the furnaces, and in other cases the foul air was carried up iron pipes and discharged at a height which did not affect the attics. They had ventilated into the streets, and one of the latest modes adopted, throughout the whole of the southern main sewers, consisted simply of a ventilating shaft carried into the street through a catch-pit for mud and stones which might fall through the grating. Between the air-shaft and the catch-pit, there was a semicircular opening 2 feet 6 inches in diameter, into which a vessel containing charcoal could at any time be fitted.

All he had to say further was, that from the experience hitherto obtained, these sewers would not be "sewers of deposit," and the ventilation of them would be by no means so necessary as it had hitherto been, or as it was at the present time, in the stagnant sewers of London. The sewage would be carried off in an ever-flowing stream by day and night, and there would be no festering mass to create the foul smells, which were so dangerous to health. These were, however, the different means of ventilation which had

been provided, though they might not be absolutely required. Many gentlemen now present, who had watched the progress of these works, might have come to the conclusion that they were costly in their character and execution. When commenced, the brickwork was £14 per rod, and it had risen to £20; the work on the south side being done in gault clay bricks and Portland cement. He considered this thorough mode of executing the work was the most economical. There would have been the same amount of excavation and filling in, and the same amount of pumping, whether they had put in cheap brickwork, or the more expensive work which had been adopted, and those who had to do with works in which pumping formed so large a proportion of the whole cost knew that to execute repairs in such works would be so costly, that inferior work was not for a moment to be contemplated. He had always been an advocate of economy in drainage works, and for many years before this was commenced he had the opportunity of carrying out an extensive system of tubular drainage and brick sewers of different sizes. His reason for making inexpensive branch sewers had been, that for one brick sewer of large size it was practicable to make eight times the length of smaller sewers of sufficient size to serve any purpose for which branch sewers were required. He had carried out the whole of the southern sewers, and he thought one of the most satisfactory features of Mr. Bazalgette's scheme was, that it had been executed in an efficient, though perhaps costly manner. Taken in connection with the branch drainage, yet to be carried out, it must, he thought, be regarded as the best solution that had yet been proposed of an extremely difficult question.

With respect to the earlier features of the scheme, he would take this opportunity of stating that in 1850, when Mr. Frank Forster and Mr. Robert Stephenson entered upon this subject, and before it came under the notice of Mr. Haywood, those gentlemen had well considered the questions of outfalls, rainfall, the proportion of the latter it would be desirable to attempt to carry away by the sewers, the water-supply both present and prospective; in fact, all the main points of this large question. At the same time he did not consider that this detracted from the merit due to Mr. Bazalgette in the prosecution of this scheme. As far as the south side was concerned, with which he (Mr. Grant) was more familiar, Mr. Bazalgette had added the high-level sewer, which carried off by gravitation the water from the Crystal Palace down to Crossness, where the sewage had only to be pumped once. That was an important feature which entitled Mr. Bazalgette to the highest credit.

Mr. John Aird, Jun., would take this opportunity of indorsing the remarks of Mr. Grant, with regard to the works on the south

side of the Thames. Of those works, he could say with confidence, that they had been carried out in the highest style of construction, and no expense had been spared, as far as it could be usefully applied.

In reference to the system of subways constructed in Paris, Mr. Bazalgette had designated it as a costly addition to the sewer-works, and one which had not been justified by the practical results obtained from it, the principal object being only to carry gas-pipes and water-pipes. Yet the same plan had been adopted in the new street in Southwark, and was also proposed in the Thames embankment, in both cases, as a separate chamber over the sewer, the expense of which would, he believed, far exceed the Paris plan. At the same time he was strongly of opinion that the system of subways was one which could never be admissible, or be carried out with any good practical results. It would doubtless be remembered, that at the time the question of subways was under the consideration of a Parliamentary Committee, M. Belgrand, the principal engineer in charge of the sewers of Paris, came to London to give evidence before that Committee, and he stated, that subways were found to be most objectionable, and that they had been abandoned in Paris, in consequence of the accidents, and other inconveniences which they had occasioned. With regard to the prices paid for the works in Paris, he only wished contractors in this country could obtain the same figures as were mentioned. They so far exceeded all previous ideas, that he thought there must have been some error in putting those figures forward.

With respect to the sewers on the southern side, with which he had been principally and intimately connected, he had much pleasure in saying, as a young man, addressing other members of the profession younger than himself, that he had derived great experience and advantages from the part he had taken in the execution of those works, and which he believed would be most useful to him in after-life.

In executing the works on the south side of the Thames, the sinking of the cylinders was always adopted previous to the commencement of the works, even before the way in which the work itself was to be done was determined. These cylinders were sunk at spots quite away from the line of the works, and to a depth considerably below that to which the work was to be extended. By this means. the precise nature of the ground, and the amount of pumping-power that was required to master the water, were at once ascertained, and then, after thoroughly draining the ground, the works were commenced. In the prosecution of these works, the value of such a system was greater than he could well express; it enabled the Engineer to know exactly what difficulties had to be

contended with, and when the work was proceeded with, it could be executed with certainty.

There was another point of importance for which he must give Mr. Grant credit. A drain-pipe, and in some cases two drain-pipes, were carried underneath the whole of the work, and securely bedded in concrete, and this was found to be of the greatest value in getting in the foundations, which were thus done in a perfectly dry condition. With regard to the cement-testing, when the walls were commenced he certainly thought the testing was somewhat too rigorous, and that the strictness with which it was conducted was trouble thrown away; but eventually, experience showed that was not the case, as at times, when the works required to be pushed, such cement was used as was at hand, and that was done sometimes, he admitted, without the knowledge of the Engineer; but afterwards it could be always seen, from the work itself, which cement had been tested and which had not.

With respect to the cost of construction, he could state that, with few exceptions, they were executed within the contract price. One of these exceptions occurred in a portion of the work on the premises of the Deptford Gasworks, where it was intended to put up a gasholder. To facilitate this, the work of the sewer underneath, for a length of 130 feet, was commenced. Unfortunately, the contractor was not able to carry it out; his firm then undertook the work and completed it. The estimated cost was about £2,000, whereas it actually cost upwards of £16,000. While speaking of estimates, he would like to mention, that his firm had had the honour of carrying out four contracts under the Metropolitan Board, and on the whole he might say there had been a saving rather than an addition to the contract amounts.

Mr. Vignoles said that he would follow up the remarks that had been made as to the alleged prices paid for the Paris works. He had had much experience of works on the Continent, and he ventured to say that in no part of the world was drainage work done so well and so cheaply as in England. The annoyances and the vexations which contractors had to put up with, under the system of engineering in France, were such, that he was not surprised at any amount of cost; and no greater proof of this statement could be afforded, than the fact that it required £30,000 a year to clean out the Paris sewers.

Mr. Bidder, Past-President, said that, indirectly, he had taken part in this subject, at an early stage, on account of his intimacy with the late Mr. Robert Stephenson, and finally, in connection with Mr. Hawksley and Mr. Bazalgette, by producing the Report which had the effect of settling the course of legislation on the question.

Before, however, making any remarks upon the Paper, he thought

it would be most ungracious, if he omitted the present opportunity of congratulating the Author on the completion of the scheme. Mr. Bazalgette had achieved a great work; he had made a reputation which was now world-wide, and which would be lasting; and he was sure, from what he knew of him, that he would be the last man to deny a due share of merit to anybody concerned in the early inception of the scheme. The question of the Metropolitan Drainage, and the purification of the River Thames, had gone through a great variety of difficulties, moral, political, and physical, and had it not been for the determined and resolute interference of Mr. Robert Stephenson, in putting an end to many of the schemes which overloaded this great question, he much doubted whether the Institution would have been able, at the present time, to congratulate Mr. Bazalgette on the completion of the works.

The one great question, which everybody thought himself competent to deal with, was the drainage of the Metropolis, the purification of the River Thames, and the Utilisation of Sewage. The discussion of the subject had gathered round it numerous inventors who adopted this, as a means of earning notoriety, and at various periods the newspapers enunciated schemes which violated all common sense and outraged all mechanical science. Water was to flow along a pipe 70 miles long; it was to flow through a pipe without any power, from London to Southampton. Because persons were in the habit of saying of every place that they went down to it from London, it was therefore thought that the water would go down there too. Then commission after commission was appointed. Mr. Hawkshaw attended one commission, which resigned, because the commissioners were called upon to carry into effect a particular proposition, which, as was to be expected from men of their standing, they would not do. The question then got into a state in which nothing could be done with it; it was referred from one to another, and at last it got into the hands of Mr. Hawksley, Mr. Bazalgette, and himself, to make a final report upon it. Personally, he claimed no credit, for he initiated no scheme; but if he took any merit at all, it was, that, with the other gentlemen, he had carried out the resolution that they began with, that they would not be tempted to consider any scheme of their own, but confine themselves to that which had been initiated by Mr. Frank Forster, and perfected by Mr. Haywood and Mr. Bazalgette, after more intimate knowledge of the facts on the subject; and which came to their consideration with all the latest information. All that they had had to do was so to fortify the scheme, so as to justify the Legislature, in giving it their sanction, and in empowering the Metropolitan Board of Works to carry it into effect. The first thing he recollected in connection with it, was the fact of Mr. Stephenson, Mr. Forster,

and some other gentlemen, having to consider a great number of plans, which had been invited by advertisement from everybody in the country. Incidentally he must protest against this method of draining the intellect of the country, because it occupied time to no useful end, and cost great sums of money. The result was, tha beyond the present scheme, the only one sanctioned was that which was propounded by the President of the Institution, Mr. M'Clean, and which, in fact, carried out, to some extent, the principle adopted in the Metropolis Sewage and Essex Reclamation Bill of this Session.

Before going into the main question, he would observe with regard to the works, that the only criticism he had heard was, that they had been executed in a style superior to the requirements of the case; but he considered that Mr. Bazalgette was quite right in what he had done. He did not know that he would have been right, if he had been acting for a body of shareholders. If he had had to meet such a body on the first occasion without a dividend, they would have looked out for a victim, and the first victim would have been the Engineer, who would have been denounced if he had put a bit of carving, or a useless piece of stone anywhere on the works; but Mr. Bazalgette had been carrying out a great public work. There might be some little complaint about the rates, but the desire of the public had been satisfied by the universal approbation which the works had excited. He believed, therefore, that Mr. Bazalgette was quite justified in completing the works in the style he had, and he only wished that he could get some public money to deal with in the same way.

He thought there could be but one opinion, that the drainage of London had been most successfully accomplished; but the question of the purification of the Thames had yet to stand the test of experience, and there were some points connected with that subject which he should like to bring under the consideration of the members. He had been professionally connected with works on the River Thames ever since the year 1825. He was then occupied upon the London Docks, and he remembered perfectly well, as no doubt some others did, a bathing-machine being established on the west side of the Blackfriars Bridge. He remembered the London Docks themselves being choked with fish; the water for the supply of the ships was taken in from the river, just opposite the docks. The water, for the supply of the East Indiamen at Blackwall, was taken in by a pumping-engine on the old wharf, which pump was worked at low water, and another great thing was, that in those days, the whitebait was caught opposite Blackwall. But what was the state of things at the present day? The bathing-machine was a matter of mere history; the London Docks, instead of being choked with fish, were full of offensive water, in which only the very lowest form of animal life could exist;

the whitebait had receded to Gravesend, and the sea-water, which then scarcely reached above Blackwall, had at present been detected as high up the river as Chelsea. All this, indicated two things, that the sewage of London had driven the whitebait lower down the river, and that, from the river having less fresh water, owing to the greater drainage of land, and the removal of old London Bridge, the salt water had been allowed to permeate farther up. Besides this, there had been a large and growing population on the banks of the river, all the way from London up to Oxford; at Kingston, Richmond, and other places, all of which had been seeking to pour their sewage into the Thames. The only part of the work which had not been tested, was, whether pouring the whole of the sewage into the river at Crossness would relieve the river from the presence of the sewage within the Metropolitan District. Of course this would have no effect upon the sea-water, which, he believed, with the completion of the Thames Embankment, would find its way still higher up the river. During last summer, some sewage from the north side was thrown into the river at low water, and there was a complaint at Woolwich. Whether that complaint was entirely due to the sewage, or not, Mr. Bazalgette would probably be able to state; but the sewage was now to be poured in on the ebb-tide, and into a volume of water enormously in excess of the sewage, and the apprehension was, that the salt water would still be found as high up the river as Chelsea, and that the sewage would, in some form or proportion, also find its way in the same direction; but how far it would be offensive, was entirely a matter of experience. It must not, however, be forgotten, that in bringing the whole of the drainage to Crossness, or to any other point on the side of the river, it had been brought where it could be dealt with. At present it was thrown into the river in such a way as to be obnoxious, and difficult to manage. He did not say it was impossible to do anything with it, but it could not be dealt with so conveniently as it could be when it was all carried to one place, as it now was to Crossness. Mr. Hemans had propounded a plan for taking the sewage down to the sea. He would express no opinion upon this scheme, because it was a commercial question, but he only hoped it would be successful, because if it should be a commercial success, then the inhabitants of London would be relieved from all anxiety about it. There was, however, one point in Mr. Hemans's bill, though not a mechanical point, which he thought ought to be adverted to, and that was, that the company had a concession of the northern sewage of London for fifty years. He thought that period, or even one of thirty years, was too long, and that there ought to have been a narrower limitation. He would explain, in what way this had to do with the drainage of London. The whole of the scheme proceeded at present on the idea that

the drainage of London and the suburbs was to be entirely by sewers, and provision had been made not only for the present, but for the anticipated population. But the time might come when some other arrangement might be made, and the sewage be otherwise dealt with, and in the event of the present scheme not answering, the promoters of it ought not to stand in the way of any other appropriation of sewage which science or experience might suggest.

He now came to the great question, as to how the rivers were to be dealt with in future, and to be protected from the pollution which must occur, if the drainage were poured unrestrictedly into them. The laws of this country were all that could be desired with regard to the protection of rivers, the only difficulty, was to put those laws into operation. No better law was wanted, for the present law would protect and recognize any man's rights, so that the water which he enjoyed should be preserved to him, if he could satisfy the Court of Chancery, and that was the difficulty, as to the injury which he might sustain. What was wanted for the purity and protection of rivers was, that a body like that which was now regulating the salmon fishery, should be appointed to deal with the impurities which might be put into rivers. He knew one river in Devonshire, a beautiful stream, which all at once became turbid, and on inquiring into the cause, he found that it was from the refuse of a mine being thrown into it, by which the river was polluted, the fish killed, and the enjoyment of the adjoining property interfered with for miles. He was told, that that very mine had never paid a shilling, and was being worked at a loss, but even if it were worked with a profit, he did say, that the proprietors on the river ought to be protected, and that the machinery for doing so should be cheap and effective.

Mr. Hemans said, that it was not to be supposed that any company would spend £2,000,000 of money in bringing a project into operation, without having a guarantee, that the very foundation of the whole concern should be secured to them for a certain term of years. It was, in fact, impossible to carry out the operations without the concession.

Mr. James Lemon would offer a few remarks upon the objects and the construction of the Paris drainage ; through the medium of a professional friend, he had obtained the following information, from one of the French municipal Engineers. The house-washings and the rain-water were drained into the collecting, or other public sewers, and each house had a particular branch, which was in communication with the public sewer. The rain-water from the houses was drained by an iron pipe, the mouth of which was trapped, to prevent smell. A ventilating tube was carried up, either in the thickness of the wall, or outside of it, from the branch sewer to the top of the roof of the house. The waterclosets of the houses did

not empty themselves into the sewers, but the urinals placed along the Boulevards were, in most cases, drained directly into the sewers. There had been a project to connect the drainage of the water-closets of all the houses with the sewers, but at present it was only carried out in a few isolated cases. These statements confirmed the account given by the Author.

Then, as to the form of the French sewers, it was curious that a nation, which has produced some of the most eminent authors on hydraulics, should have lost sight of one of the first principles, that of obtaining the maximum hydraulic mean depth of flow in the sewers in dry seasons: for which purpose the egg-shape was one of the best forms.

Now, what was the case in the French system? According to the diagrams exhibited by Mr. Hederstedt, many of the sewers had flat bottoms, or nearly so. For example, the drainage space of the sewer under the Boulevard Sebastopol was 4 feet wide, and only 2 feet 1 inch deep, which he would instance, as one of the causes of the silting up of the sewers.

Another of the causes of deposit, was the want of properly-constructed gullies. In Paris, the streets were often cleansed twice in the day, and the sand from the surface was washed directly into the sewers, by a vertical channel, constructed in the side of the subways with an opening on the surface of the street under the kerb, but if the gullies were constructed on the metropolitan system, this flow of sand into the sewers would be prevented.

There could be no doubt, that the proposed improvements in the water supply of Paris, would produce a reform in the present defective state of the watercloset arrangements; if that were the case, how was the increased consumption of water to be disposed of? The present cesspools would not contain the sewage, without connection with the sewers, as they were constructed of masonry, in the best manner, and no liquid matter could percolate through the walls.

As an instance, he would take the number of houses draining into one cesspool, at 12, the number of persons at 10 to each house, the water consumed, and the urine, at 2 gallons per head per diem; hence $12 \times 10 \times 2 = 240$ gallons per day $= 1{,}680$ gallons per week, for which there would be required a cesspool about 28 feet in area by 10 feet deep, which would also require emptying once a week; or if the population were taken at 1,700,000, and the estimate made of 2 gallons per head per diem as before, cesspool accommodation would be required equal to $1{,}700{,}000 \times 2 = 3{,}400{,}000$ gallons per day $= 95{,}200{,}000$ gallons per month; a quantity which would require a cubic capacity of 15,232,000 feet, which was about $2\frac{1}{2}$ times the contents of the northern reservoirs at Barking. Taking the cesspools at the same depth as those reservoirs, 24 acres of the city of Paris would be occupied by cesspools, which would

require emptying every month, involving a large annual outlay, besides the annoyance of the carts, &c., passing through the streets. These data showed, that a system of cesspools with good water supply, without connection with the sewers, would be exceedingly unwise. Moreover, in the foregoing calculations, the drainage from the waterclosets only had been included, whereas in practice, it would be found that a large quantity of the house-washings would also be thrown down the closets. Supposing that the whole of the drainage of every kind was admitted into the sewers, which must ultimately be the case, then it would be found that the main sewers would be inadequate to carry off the sewage, without overflowing the floor of the subway. For example, the collector under the Boulevard Sebastopol had a drainage space of about 8 feet area, and it would be required to take the sewage of 400,000 persons.

But, if the total quantity of sewage were estimated at the London rate of water supply, viz., 5 cubic feet per head per diem, discharged in 12 hours, then, by the formulæ of Mr. Beardmore, there would be rather different results, showing that here would be required an area about double that provided, without considering the rainfall. In the Paris system, the acquisition of a good water supply would involve the deepening of the invert, or some other reconstruction of the égout collector. He would refer to the great size of the sewers and subways in the Parisian system: if a comparison were made of the sewer and subway under the Boulevard Sebastopol, with that lately constructed in London, in the new streets, it would be found that the area of sewer was nearly the same, whereas the area of subway was nearly three times that of the London section. The cost of the Paris subway and sewer, at the London rate of prices, would be about £7 per foot run; that of the London sewer and subway had cost about £2. 10*s.* per foot run. It was true, that the French subway was designed to take the storm-waters, but overflow sewers might have been constructed at much less cost, and with better sanitary results.

Mr. Bazalgette, in reply, said, that in the first place he was glad to be enabled to express his thanks for the support which he had received from the late Mr. Robert Stephenson, especially at a period when he had met with much opposition, in carrying out the arduous works, which formed the subject of the Paper, in addition to the support which he had also received from Mr. Bidder and Mr. Hawksley. On bringing the subject before the Institution, he found, that there were now a great number of persons who claimed to be the "pioneers" of his design, and it was a source of regret to him, that he had not been aware before, of the existence of many of the schemes which had been referred to, for it would have saved him many anxious days and sleepless nights, in working out for himself, that which it was now alleged, had all been done and

prepared before. All he could say was, that if there were any gentlemen who had previously designed, or worked out his scheme of drainage, and who would produce their drawings and designs, and show them to be similar to those he had presented to the Institution and had executed, he should be most happy to acknowledge the fact. It was, at any rate, satisfactory to him to find, that they approved of what had been done, and it would also have been very satisfactory to him, supposing the works had failed, to have found so many gentlemen ready to come forward, and say—"Well, never mind, we designed the same thing, and are ready to share the opprobrium with you."

But, there were one or two points, raised in the course of the discussion, to which he must briefly allude, and the first was a leading principle, viz., of separating the sewage and the rainfall. It had been said, exclude all rainfall from the sewerage system. He could imagine, that in a village, or in a small town the sewage of which had previously been drained into cesspools, but which had had sewers provided for the rainfall, it might be advantageous to construct a system of sewers for the house-drainage alone, and to allow the rainfall to pass off through the old sewers; but, if this principle were attempted to be applied to the metropolis, it could not be carried out. It would involve what he had alluded to in his Paper, a double system of drainage; it involved going into every house in the metropolis, and telling the owner, that his house must be redrained, and that he must go to the cost of it. At the present time, one house-drain took the sewage from within the house, and the rainfall from the roof and the area, and before these could be separated, it would be necessary to construct a double set of house-drains and sewers. He had investigated the subject very carefully, because it was one of the theories which he had to contend against for some considerable time, and he found, that besides the revolution, which such wholesale interference with house property would cause in London, the scheme would be altogether impracticable. The advantage of a large volume of rain-water which now cleansed the sewers would be lost; the fall in the sewers would have to be increased to compensate for this, thus leading to an increase in the lifts and pumping power, and the whole undertaking would involve an outlay of no less than £10,000,000 or £12,000,000 of money.

It had been alleged, that the reservoirs would collect deposit and become a nuisance, and that the money would have been better expended in carrying the sewers lower down the river. He only wished that those who took this objection would, as he had done that day, walk into the reservoirs, just after the sewage had been in them; had they done so they would have found that there was not the slightest deposit collected in them, and if there had been, nothing would have been more easy than to have removed it

by allowing the tide at high water to run into a culvert, prepared for the purpose, and then by opening a pen-stock, to wash the deposit completely away. The reservoirs, which contained the sewage till the time of high water, and then discharged it into the Thames, were equal, in effect, to the construction of twelve miles of sewers, because the tide, from high water to low water, carried the sewage twelve miles lower down the river, whereas not even six miles of sewers could have been constructed for the cost of one of the reservoirs. The minimum fall of the sewers was two feet per mile, but the fall in the river was only about three inches per mile, at that point, and to have extended the sewers would either have involved having sewers tide-locked, which was most objectionable, or else a resort to a large increase of pumping. He conceived, therefore, for these reasons, that no other plan would have been so economical, or have answered so well, as the reservoirs which had been constructed.

He would now refer to the allegation, that it was a great mistake to conduct the sewage to one point, and that it ought to have been distributed over a number of points. If this proposal were carefully considered, it would be seen, that it would involve taking the sewage from the low districts, on the margin of the river Thames, up to the high districts, such as Hampstead, Highgate, Kentish Town, or other similar neighbourhoods, and for what purpose? Why, only enormously to increase the expense of pumping. If the sewage were conveyed to those high districts, what was to be done with it? If distributed as liquid manure there, it must be done amongst the houses, and in the streets of those thickly-inhabited neighbourhoods; but this was clearly impossible. If made to flow down to some low district, as had been done, and concentrated at a point where it could be conveyed with very little lifting, or by gravitation, over agricultural land, and at the same time at a point where it would cease to be a nuisance to the metropolis, he thought that was the cheapest and best arrangement, which could be entered into.

Mr. Chadwick's recollections of the sewers of London must be of rather ancient date. He had stated, that there were a thousand miles of sewers, of decomposing deposit, and he talked as if pipe sewers were the only means of getting rid of that deposit. It was well known that Mr. Chadwick was fond of the subject, and it was to be wished he would only go and spend a day in the sewers, for he would very soon change his present views of the state of the so-called sewers of deposit. Now that they had ceased to be tide-locked, there was no reason why there should be any sewers of deposit, for the flow in the sewers would carry off the deposit, if their inverts were only properly constructed, and the fall sufficient. The cause of the deposit in the sewers was, that in former times, as the sewage of London fell from the high districts into the low

districts, they could not discharge from the low level into the river except at low water, and therefore for eighteen hours of the twenty-four, they were tide-locked, and became filled with the deposit which Mr. Chadwick had so well described, and no doubt, decomposition was then going on; but, from the moment the new system came into operation, there was a constant discharge produced in the formerly tide-locked sewers, and they ceased to be sewers of deposit. This had been accomplished by means of the intercepting sewers and pumping stations, and he believed that Mr. Chadwick's picture was overdrawn, and that the notion that the sewers of London were now in the state he had described, was entirely erroneous. During the time the sewers were tide-locked, the cost of cleansing was very heavy, probably about £30,000 a year, and the reason was, that the labour of cleansing was exceedingly great. Men could not get into the South London sewers, except for an hour at low water, and they had not been there long, before they were driven out again, by the sewage rising upon them. He could not tell what the present cost of cleansing sewers would be, because there had not yet been sufficient experience, but he was able to say, that with a fall of two feet per mile, in one of the large sewers, it had required no cleansing throughout the year. He had now had experience of that sewer for more than two years, and he had found that the flow kept it perfectly clean, and therefore he thought he was warranted in coming to the conclusion, that wherever sewers of any size had been constructed with a proper section and fall, and a constant flow, they would require no cleansing.

From his experience of the velocity of the flow in sewers, and their power of discharge under various conditions, he was somewhat surprised to hear Mr. Chadwick come forward and tell the Institution, that the whole of the theories of the Engineers, and the experiments of eminent Engineers of olden time, were fallacious; that a Trial Works Committee had been appointed when he was a Commissioner of Sewers, and that that committee had instituted experiments, which entirely upset the calculations and theories of Engineers of ancient date. He happened to know something of this Trial Works Committee, for he had examined their minutes and reports, and Mr. Chadwick would excuse him if he mentioned some facts respecting it. Mr. Chadwick had stated, that one experiment showed how, in a main pipe-sewer with seven branches, or eight branches, each contributing additional sewage to that which was already in the main; the velocity of flow was so increased, that the additional quantity did not increase the volume in the main; after that extraordinary result it was certainly surprising that Mr. Chadwick did not put in a few more junctions, and at last arrive at the conclusion, that the increased velocity had so reduced the volume that there was no want of an

outlet. But he was not astonished at the results of the Trial Works Committee, for he found that the experiments were mainly conducted by persons never before heard of, as Engineers. He had looked into the results discovered through that Committee, and in the margin of the book kept by it, he had seen the observations of Mr. Cowie, a very distinguished member of that Committee, and an able mathematician; he had seen, in his writing the word "impossible" affixed to the record of some of the experiments. He did say that it was absurd to tell the Institution that such experiments were to be relied upon, as upsetting the careful and well-tried experiments and inductions which had been successively worked out upon a large scale, and verified, by Engineers of standing and repute. He had imagined that this was one of the bubbles of the day which had long since burst, and he was surprised to hear the Trial Works Committee now upheld at that Institution.

He came next to the observation, that the addition of the intercepting sewers to the sewers of London was likely, in times of dry weather, to lead to some pestilence, or disease from the stagnation of the sewage. How was it that, with the 1,300 miles of sewers at present existing in London, some of which were formerly tide-locked, and all constructed for carrying off the largest rainfalls, while the amount of sewage in them and consequently the flow was very small in dry weather, the addition of eighty miles which would relieve all stagnation and carry off the sewage as fast as it was poured in—how was it that these relieving sewers could produce the disease and the evil results as foretold? In the old sewers, constructed to carry off both extraordinary rainfalls and a comparatively small amount of sewage, the scouring power in dry weather was but small, but the intercepting sewers were half filled with the maximum flow of sewage in the period of dry weather, and, as was well known to the Institution, a circular sewer, half-filled, had the same scouring power as a circular sewer quite filled; he contended therefore that those sewers during the maximum flow in dry weather had as good a scouring power as they would have during a storm. He thought that argument was unanswerable, and therefore not only was theory strongly in his favour to prove that the sewers would not collect deposit, but experience on this point had already shown that the intercepting sewers produced a constant flow in the formerly tide-locked sewers, and thus relieved the metropolitan district from that stagnation of the sewage which had previously existed, and which had actually produced the diseases now apprehended.

With respect to the comparative pumping power at Deptford and Crossness, it must be borne in mind, that at Crossness, the maximum lift and maximum flow could never occur together, and during the period of maximum flow, if the engine did not take the whole

of it, the main outfall sewer would act as a reservoir for the time being, until the lift was reduced, and the engines were capable of taking it; whereas at Deptford, the whole of Bermondsey, Rotherhithe, Lambeth, and that low district, was entirely dependent on the pumping engines to relieve them from inundation, and therefore it was necessary to have a larger margin of power at Deptford.

It had been thought that the cost of the subway in the Thames embankment was greater than that of the Paris subways. But the plan showed that that subway formed in fact nothing more than a relieving arch to the abutment of the embankment. Engineers were in the habit, when constructing long piers, of putting an arch in the centre to save brickwork, and the subway was a work much of that character, and was constructed at little or no additional cost.

Respecting the purification of the river Thames, there must be apparent to every one a striking contrast between the old and the new system of discharge into it. Under the old system the sewage was only discharged at London during the time of low water, when there was but little water to dilute it; it was then carried up the river to Richmond, and came back and got mixed with the next day's supply of sewage, and so the evil went on, from day to day; but compared with the present state of things, when the sewage at Barking and at Crossness was discharged at high water, 14 miles below London, and was carried with an immense volume of water to a still greater distance from London, there was no doubt, that the new system was a vast improvement on the old.

As to the complaints made at Woolwich last year, he would say, that at that period the sewage of the south side of the Thames was being discharged into the Thames at low water, and had been until that very day. It was, therefore, until now, subject to the objections, which applied to the tide-locked sewers under the old system; that was to say, the outfall sewer was tide-locked, and accumulated deposit; the sewage discharged at low water flowed back to London, and no doubt was objectionable to Woolwich for the time being, but he did not believe that a nuisance was ever caused at Woolwich, or at any other locality, by the discharge of the northern sewage at high tide at Barking.

With regard to granting the sewage to a company for the period of fifty years, it had been thought objectionable, because some other scheme might be discovered which would be more useful and beneficial, therefore the Board of Works should not have granted the concession for so long a period. But experiments had been tried with regard to the utilisation of sewage, for the last ten years, or fifteen years. There had been precipitation by lime, by perchloride of iron, and by almost every other means

which could be thought of; one after another had failed, and doubtless years might elapse before there would be a better solution of this problem. But there had been some successful results of the application of sewage in a liquid form; there were some eight or nine towns where it had been so applied, and surely it would be unreasonable to expect any body of men to expend £2,000,000 of money, with the prospect of the whole expenditure being sacrificed after some short period. Besides this, it should be borne in mind, that the arrangements made, had in view the benefit of the ratepayers of the metropolis, and yet they were not called upon to expend one penny in this great utilisation scheme. They had spent their money only in purifying London, and the public money had not been speculated with, but the Company had undertaken to share with the ratepayers, in liberal proportions, the profits of the scheme.

Mr. M'Clean, President, said that he would ask the Members to join with him in congratulating Mr. Bazalgette on the successful manner in which he had carried out the works, and on the excellence of the workmanship, and the perfectness of the scheme.

March 21, 28, and April 4, 1865.

JOHN ROBINSON M'CLEAN, President,
in the Chair.

The discussion upon Papers No. 1,126, on "The Drainage of Paris," and No. 1,229, on "The Main Drainage of London," was continued throughout these evenings, to the exclusion of any other subject.

At the Meeting of March 28th, His Royal Highness Albert Edward, Prince of Wales, was elected by acclamation an Honorary Member.

At the Meeting of April 4th, the following candidates were balloted for and duly elected:—Frederick Ashmead, William Henry Coddington, Osborne Cadwallader Edwards, Henry Osburn, Devonsher Jackson Scott, William Burton Wade, and Matthew Woodifield, as Members; William Podmore Bayliss, Major Andrew Clarke, R.E., William Naylor, John Charles Raymond Okes, Thomas Oliver, Captain William Coles Phillpotts, R.E., Alfred Robson, George Henry Smith, and James Young, as Associates.

April 11, 1865.

CHARLES HUTTON GREGORY, Vice-President, in the Chair.

No. 1,130.—"On the Festiniog Railway for Passengers: as a 2-feet gauge, with sharp curves, and worked by locomotive engines."[1] By HENRY WHATELY TYLER, Capt. R.E., Assoc. Inst. C.E.

THE Festiniog Railway, or tram-road, was originally constructed under the Act 2 Will. IV., cap. 48 (23 May, 1832), and shortly after the passing of that Act. It commenced at a quay, near Portmadoc, in the parish of Ynys-cynhainain, in the county of Carnarvon; and after running for thirteen miles through a wild, hilly and beautiful country, terminated at the slate quarries of Rhiwtryfdw and Duffws, in the parish of Festiniog, in the county of Merioneth. The objects of its construction were to open out "a more direct, easy, cheap, and commodious communication between the interior of the principal district of slate and other quarries of the county of Merioneth, and the various shipping places at and within the said several counties of Carnarvon and Merioneth;" and to "greatly facilitate the conveyance of coals, and other heavy articles to the several slate, and other quarries and mines in the said district, and the conveyance of the slates, copper, and other ores, and other productions of the said slate and other quarries and mines, and of the surrounding country, to the seaside," and that it should be otherwise "a work of great public utility."

The Festiniog Railway Company, having been duly incorporated, received power to make the railway, or tram-road, and to construct the necessary works; but upon the conditions that the railway was not to pass within eighty yards of Plas-tan-y-bwlch, that no stones or materials were to be raised within half a mile, or any buildings erected within one mile of Plas-tan-y-bwlch, and that all the steam engines employed were to consume their own smoke.

The lands or grounds to be taken, or used for the purposes

[1] The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

specified in the Act, were not to exceed four yards in width, except where it was necessary for carriages or wagons to "turn, remain, or pass each other," or for buildings or appliances to be erected, or for embankments or cuttings to be made, or for wharves, or goods stations; and no work, or building was to be above sixty yards in breadth at any place, except on commons or waste lands, or by consent of owners.

The Company was not to occupy more than was absolutely necessary of the Traeth Mawr embankment near Portmadoc; the gauge between the rails was not to exceed three feet upon that embankment; the surface of the embankment was not to be disturbed more than one foot in depth, and the ordinary traffic upon it was not to be interrupted.

The estimated cost of the line was £24,185 10*s*., and the Company was authorised to raise £10,000 by loan. Powers were afterwards granted to raise further sums of, £12,000 by shares, and £4,000 by loan, so that the total Parliamentary capital of the Company is £50,185 10*s*.

The population of the district, in 1832, was very limited, and the line was therefore laid out in an economical manner, and on a gauge of only two feet between the rails. But from time to time, as the traffic increased, many of the curves have been eased, diversions have been made, at great expense, for the sake of obtaining better gradients, and avoiding steep inclines; and improvements have been effected in the permanent way, though without any alteration of the gauge. The difference in level between the terminus at Portmadoc, and the mountain terminus at Dinas is 700 feet, and the average gradient for $12\frac{1}{4}$ miles, from that mountain terminus, to the Traeth Mawr embankment, near Portmadoc, is 1 in 92. The steepest gradient on the portion now used for passengers is 1 in 79·82, and the steepest on which locomotive engines are employed is 1 in 60. Some of the curves are exceedingly sharp, having radii varying respectively from 2 chains to 4 chains. The maximum super-elevation allowed for the outer rail, on a curve of 2 chains, is $2\frac{1}{2}$ inches, for a speed of 8 miles per hour.

As the slate quarries are at different altitudes in the mountains, the slates are first brought down the quarry inclines to the railway, and the trucks are then collected and forwarded in trains to Portmadoc. These trains, sometimes composed of fifty trucks or sixty trucks each, run down by the force of gravity, and are in charge of breaksmen.

Until 1863, the empty trucks, or trucks loaded with coals, goods, furniture, materials, machinery, and tools, for the quarries and the neighbourhood, were drawn up by horses, which were brought down in the trains, as on some of the colliery, or mineral lines in the North of England.

As the traffic increased, and after the railway had been much improved, the practicability of employing locomotive engines on so narrow a gauge was frequently discussed; but the project was more than once abandoned, in consequence of the apparent difficulties, and of the adverse opinions expressed by the Engineers who were consulted. At length the continued increase of the slate traffic, and of the trade of the neighbourhood, caused it to be revived; and Mr. England was employed, under Mr. C. E. Spooner, the Secretary and Engineer of the Company, to design an engine for the purpose. Two locomotive engines were accordingly placed upon the line in June, 1863, and were found to work so successfully that others have since been supplied. The Company now possesses four engines, which have run (up to February, 1865) 57,000 miles without leaving the rails.

During the past autumn, the Company carried passengers experimentally, without taking fares, and, at the commencement of the present year, the line was regularly opened for passenger traffic. In ascending from Portmadoc, the passenger-carriages are drawn by the engines with other vehicles, the passenger-carriages being placed between the empty slate-trucks, which are always last in the trains, and the goods-wagons, which are next behind the tender. In descending, the loaded slate-trucks, with empty goods-trucks attached behind them, run first in a train by themselves; the engine follows, tender first; and the passenger-vehicles, detached from the engine and tender, and at some little distance behind them, bring up the rear, with a break van in front, and a guard on a platform outside it. The speed is limited to about six miles per hour, in passing round the sharpest curves, and ten miles per hour on other parts of the line. The passenger-guard, standing outside his van, is always ready to slacken speed, by the application of his break, in approaching level crossings and sharp curves, or in obedience to a signal, or in the event of an obstruction on the line; and the different trains, or portions of the trains, are able to follow each other, at the above moderate speeds, more closely than could be done, with safety, on ordinary railroads.

The engines, though on a much smaller scale, are of a somewhat similar pattern to those which have been found so useful by contractors. The wheels are 4 in number, and are coupled together, 5 feet apart, and are 2 feet in diameter. The cylinders, which are placed outside the framing, are 8 inches in diameter, with a length of stroke of 12 inches, and are only 6 inches above the rails. The maximum working pressure of the steam is 200 lbs. to the square inch. Water is carried in tanks surrounding the boilers, and coal in small four-wheeled tenders. The heaviest of these engines weighs $7\frac{1}{2}$ tons in working order, and the cost was £900 each. The average load taken up, at a speed of about 10 miles per hour

on the ascending journey, is 50 tons, including the weights of the carriages and trucks, but exclusive of the weights of the engine and tender. In fact, the actual performance of the engines, exclusive of considerable shunting, is to convey daily, on the up journey to Portmadoc, along the Traeth Mawr embankment, average loads of 260 tons of slate, all the empty slate trucks from Portmadoc, 50 tons of goods, and 100 passengers, besides parcels, at an expenditure of 17 cwt. of coal and coke for two engines, or about 0·75 lb. per ton per mile, the average ascending gradient for 12¼ miles being 1 in 92, and there being a level portion for about three quarters of a mile near Portmadoc.

The high pressure at which these engines are worked, combined with the small driving wheels, gives them a surprising amount of power for their size, and adapts them well for convenience in starting and for working at slow speeds. The centre of gravity also has been kept as low as possible, with a view to steadiness on so narrow a gauge. But their short wheel-base, and the weight which overhangs the trailing wheels, imparts more or less of a jumping motion in running, which might be avoided by the addition of trailing wheels, working, perhaps, in radial axle-boxes, to steady them. Efficient safety-guards, similar in form to snow-ploughs, have been added in front of the engines, behind the tenders, and under the platforms of the break vans.

The passenger carriages are necessarily of a different construction from those in ordinary use on railways, and are also low. Their dimensions are 6 feet 6 inches high in the middle above the rails, 10 feet long, and 6 feet 3 inches wide, outside measurement. Each carriage has 4 wheels, 1 foot 6 inches in diameter and 4 feet apart, from centre to centre of the axles. There is a longitudinal partition down the centre, and the passengers sit back to back, so as to avoid causing an overhanging weight outside the rails. The second and third class carriages cost £100 each, and do not differ from the first-class carriages, which cost £120 each, except in their fittings. The springs are volute, and the axle-boxes, which are under the seats, are easily lubricated on the removal of a small door opposite to them. Each carriage will convey 10 passengers. No platforms are required, as the floors of the carriages are only 9 inches above the rails; and, there being no break in the longitudinal partitions, the passengers get in and out through the doors on both sides.

There are also some open cars for summer use, of similar construction, as regards the under-framing, and of similar length, to the above carriages; but without sides and roof. The passengers are strapped into these carriages by means of longitudinal and cross-straps.

It is a question whether longer carriages on 8 wheels and

bogie frames might not be used for sharp curves on other lines of unusually narrow gauge with advantage. But it is considered, that carriages of greater length than 13 feet would be inconvenient for moving about at the stations. If the curves on the line had not had any radii of less than 5 chains, the length of 13 feet, with 6 feet 6 inches centres for the axles, would have been adopted. The couplings are central, similar to the screw-couplings in common use, are 15 inches above the rails, and work upon volute springs. The buffers are also central, are $4\frac{1}{2}$ inches above the couplings, and work against a curved spring, 2 feet long. The system, which the Author has observed to work successfully on the Continent, of a single link, with a double spring connected with each draw-bar, would probably be found well suited to act at the same time as buffer and coupling, at slow speeds, on railways of this description.

The permanent way is now laid with rails weighing 30 lbs. to the lineal yard, and in lengths of 18 feet and 21 feet. The rails are supported in cast-iron chairs, which weigh 13 lbs. at the joints, and 10 lbs. each in the intermediate spaces. The sleepers are of larch, 4 feet 6 inches long, and averaging 10 inches by 5 inches in section under the joints of the rails, and 9 inches by $4\frac{1}{2}$ inches elsewhere. They are placed 1 foot 6 inches apart, on each side of the joints of the rails, and 2 feet 8 inches apart in the intermediate spaces. The rails are secured in the chairs by wooden keys, and the chairs are fixed to the sleepers by wrought-iron spikes, $4\frac{1}{2}$ inches long by $\frac{5}{8}$ inch diameter.

There are 17 bridges under, and 5 foot bridges over the railway, as well as numerous stone viaducts across the valleys. Most of the smaller openings are covered by girders, or rather slabs, of slate. There are also two tunnels, one 60 yards long, and the other 730 yards long; the former through hard shale, and the latter through syenite rock, which is sufficiently solid to require no lining.

The Company has, of course, had many difficulties to contend with in transforming a horse-tramway, thirty-three years old, into a passenger line worked by steam locomotives; and not the least of these difficulties has arisen from the narrowness of the works. The stone walls, with which the greater part of the line is fenced, as well as the abutments of the bridges and the tunnels, leave less width than it would be desirable to provide, on any lines of an extra-narrow gauge which may be constructed in future. The carriages, being 6 feet 3 inches wide, overhang the rails by about 2 feet on each side; and this renders it desirable that the works at the sides of the line should be at least 4 feet 6 inches from the rails, and that a total minimum space of 11 feet 6 inches, or 12 feet, should be preserved in the clear between the abutments

of bridges and other works, for a single line of rails. These dimensions would, of course, vary with differences in the width of the gauge and the width of the carriages, it being desirable, on all new lines, that a minimum distance of 2 feet 6 inches should be preserved between the sides of the carriages and the works; and the width of the works would therefore depend, not so much upon the gauge of the rails, as upon the dimensions of the carriages employed upon them.

In like manner, where the line is doubled, or where sidings occur, it is necessary that an intermediate space of 7 feet should be allowed, to admit of the doors of the carriages in one train swinging clear of the vehicles of another train, and for other reasons; their dimensions also varying according to different widths of gauge and carriages.

The Author conceives that the employment of locomotive engines on this little railway, and the opening of it for passenger traffic, are not only highly interesting experiments, but are likely also to be followed by important results. There can be no doubt, that this country owes her abounding prosperity of recent years mainly to the rapid development of railway communication, and that the increase of that prosperity in future years will depend much upon the facilities for, or, in other words, upon the cheapness and rapidity of transport which may be provided for passengers and produce, between all parts of the kingdom. These further facilities must be derived, partly from improved carrying powers on some of the existing railways, and partly from the construction of new railways. Every new line in an agricultural, a manufacturing, or a mineral district, tends to stimulate production, to provide means of employment for an increasing population, to add to the supply of food, and to bring into use sources of wealth which would otherwise lie dormant. There are still, doubtless, numerous districts where railways on a gauge of 4 feet $8\frac{1}{2}$ inches may be profitably made; and, indeed, the number of miles of such railways annually projected and carried out has, of late, been increasing rather than diminishing. Although only 477 miles were opened for traffic during the past year as against 771 miles for 1863, yet 4,270 miles were projected for the present session, against 3,099 miles for the session of 1864. But there are also many other districts in which lines of cheaper construction are required. Railways on the gauge of 4 feet $8\frac{1}{2}$ inches can hardly be made more economically than at present, as far as regards the permanent way, or the works. Cheap lines necessitate steep gradients, which require heavy engines, and heavy engines require substantial bridges and a strong permanent way. On the other hand, with a narrower gauge, lighter rails and sleepers, less ballast, and cheaper works generally may be employed; sharper curves may be laid down; very heavy gradients may,

particularly in mountainous districts, be more cheaply avoided ; and lighter engines, with lighter vehicles, may be made to do all the work required, where high speed is not demanded, and where the traffic is not heavy.

The Norwegian government, as appears from an interesting report by Mr. C. D. Fox, has constructed, and has in full operation, two lines, the one from Grundsett to Hamar, 24 miles long, and the other from Throndhjein to Storen, 30 miles long, both on a gauge of 3 feet 6 inches. The former, with gradients of 1 in 70, and curves of 1,000 feet radius, through a moderately easy country, has cost, including rolling stock and stations, £3,000 per mile. The latter, through a more difficult country, with gradients of 1 in 42, and curves of 700 feet to 1,000 feet radius, has cost £6,000 per mile. The rails weigh 37 lbs. to the lineal yard, and are fished at the joints. The sleepers are of native pine timber, 2 feet 6 inches apart, 6 feet 6 inches long, and 9 inches by 4½ inches in section, and the rails are secured to them by dog spikes only. The engines weigh 14 tons, in steam, and the carriages are 9 feet 3 inches high, and 6 feet 6 inches wide. The speed is about 15 miles per hour, including stoppages. The Norwegian government is so pleased with the result, that an additional length of 56 miles of this gauge is now in course of construction, and no other gauge is contemplated for the traffic of that country.

It is, however, illegal at present to construct any passenger lines in Great Britain on a narrower gauge than 4 feet 8½ inches, or in Ireland than 5 feet 3 inches. The Act 9 and 10 Vict. cap. 87, provides (sect. 1), "that after the passing of this Act it shall not be lawful (except as hereinafter excepted [with reference to broad gauge railways]) to construct any railway for the conveyance of passengers on any gauge other than 4 feet 8½ inches in Great Britain and 5 feet 3 inches in Ireland ;" and (sect. 6), "that if any railways used for the conveyance of passengers shall be constructed or altered contrary to the provisions of this Act, the Company authorized to construct the railway, or in the case of any demise or lease of such railway, the Company for the time being having the control of the works of such railway, shall forfeit ten pounds for every mile of such railway which shall be so unlawfully constructed, or altered, during every day that the same shall continue so unlawfully constructed or altered ;" and sect. 7 gives power to the Commissioners of Woods, &c., or to the Board of Trade, to abate, or remove such railways, so constructed, or altered, contrary to the provisions of the Act.

It would therefore appear to be necessary, before constructing any railways for passengers on a less gauge than 4 feet 8½ inches, or before attempting to open for passenger traffic any railways so

constructed subsequently to the year 1846 (in which the above Act was passed), to endeavour to obtain, if not its repeal, at least a modification of its provisions. That Act was passed after the Report of the Gauge Commissioners, when there was a strong feeling against break of gauge, and when there was no immediate prospect of a third and narrower gauge being extensively required. But there is now an increasing demand for branch railways of a minor class. Many coal and mineral lines are in use on a narrower gauge than 4 feet 8½ inches, and others are about to be constructed with ultimate views of passenger traffic. It would therefore be an advantage if some smaller gauge were recognized; for however objectionable the existence of different gauges on important through lines of communication may be, it is quite otherwise with respect to the use of a narrower gauge for feeding branches, in districts where a similar gauge to those main lines would not be commercially practicable. Passengers change carriages, under any system, at the junctions of less important branches; and it is considerably cheaper to transfer heavy goods from one railway truck to another, than to cart them for several miles, perhaps over indifferent roads. The Festiniog Railway, on which the original gauge has necessarily been maintained, in consequence not only of its own works, but also of those of the tramways and quarry inclines running into it, is an extreme example, outdone only by the little engine which does the work of the shops at Crewe on a gauge of 18 inches; and the cost of that railway, under the peculiar circumstances of its original construction and subsequent alterations, cannot be taken as a guide for the future. A gauge somewhat wider than 2 feet would probably be desirable on any line to be now constructed, and it would hardly be worth while to desert the gauge of 4 feet 8½ inches in Great Britain for any gauge wider than 2 feet 6 inches. But whatever the exact gauge, whether 2 feet 6 inches, or 3 feet, or any other dimension that might be considered most suitable for lines of minimum traffic, there can be no question, that a system of branch lines, costing two-thirds of the branches now ordinarily constructed, and worked and maintained at three-fourths of the expense of those branches, would be of decided benefit to Great Britain and Ireland, and would be most valuable in India and in the colonies; in fact wherever there are people to travel, produce to be transported, or resources to be developed, where it would not be commercially profitable to incur the expense, in the first instance, of a first-class railway.

Captain TYLER said, having been called upon officially to inspect this railway, he thought a brief description of it might be interesting to the Institution, and he noped that description would be the means of calling forth a discussion of great use, in elucidating the important question, whether it was desirable to have a narrower gauge in this country, under peculiar circumstances of locality, and having regard to the nature of the traffic. There were already in Wales, a number of different gauges used on tramways for bringing slates and minerals down to the ports of shipment; and in other countries different gauges were springing up. In Queensland, he had been informed, 100 miles were in course of construction on the gauge of 3 feet 6 inches, and 200 miles more were projected on the same gauge. It was important to ascertain, what would be a suitable gauge in those instances where the traffic was not likely to be large. Farmers were now using portable railways, for transporting the produce of their fields, for bringing in their harvests, spreading manure, &c., and there seemed no reason why districts, which could not support a railway on the gauge of 4 feet 8½ inches, should be altogether deprived of the advantages of railway communication. The question of gauge was, in one sense, a question of speed. Speaking roughly, on a railway of 2-feet gauge, with 2-feet driving wheels, travelling might be made as safe at 20 miles per hour as on the Great Western, with its 7-feet gauge and 7-feet driving wheels, at 70 miles per hour. He had travelled on parts of this little line at the rate of 30 miles per hour with every feeling of safety. He regretted the unavoidable absence of Mr. Spooner, because it prevented him thanking that gentleman, in the presence of the meeting, for the information afforded during the preparation of this Paper, and because, if he had been present, he would have been able to give further information on the subject. Mr. Spooner took great interest in this line, and was accustomed to travel on it along the Traeth Mawr embankment in a boat-carriage, not inappropriately named "Ni l'un ni l'autre," being carried along by a sail. The preliminary expenses in first applying locomotive engines, and making numerous adaptations on so narrow a gauge, were considerable; but since the line had been in working order the following results were shown.

STATEMENT of the COMPARATIVE COST of WORKING the FESTINIOG RAILWAY by HORSES, and by LOCOMOTIVE POWER.

By Horses.

	£.	s.	d.
Contract for the carriage of slates and minerals, 70,000 tons at 8*d.*, the Contractor finding labour, grease, and oil	2,333	0	0
Contract per ton on 9,000 tons of coals, train, and other merchandise, ditto, at 3*s.*; the draught being ditto less journey . .	1.350	0	0
No passengers, and no cost for porterage	..		
	£3,683	0	0

By Locomotives.

	£.	s.	d.
Locomotive department (wages)	740	0	0
Materials for repairs of locomotive tender and van	200	0	0
Fuel, oil, and grease required for working traffic, including oil for signal lamps, &c.	636	0	0
Additional expenses and wages keeping train in repair, over above amount by horse power	296	0	0
Additional cost in keeping up permanent way	680	0	0
Additional attendance in signal men on the horse system	334	0	0
Cost of working train by Locomotive	2,886	0	0
Cost of working train by Horses	3,683	0	0
Difference in favour of working by Locomotive nearly 22 per cent.	£797	0	0

Mr. G. W. HEMANS said, he had seen this railway, when worked by horse-power, about three years ago, and was glad to hear now, that it confirmed the impression he then entertained, that the project of working it by locomotive power would be successful. The idea of using locomotives arose from the competition branch line, which was contemplated by the owners of the ordinary gauge lines, leading along the Welsh coast, and which branch was to penetrate into the slate district. He was called upon to examine as to the propriety of this branch line on the ordinary gauge, for the purposes of the slate quarry, and the result of his observation was, that for those purposes that gauge was unsuitable, and that no better thing could be devised than the existing 2-feet gauge. The small wagons on this gauge were carried over steep inclinations, of 1 in 12 and 1 in 15; and in some places of as much as 1 in 5, or in 6, so as to penetrate into every part of the immense slate quarries of Festiniog. The slates brought down on these extensive ramifications were expected, if the ordinary gauge branch were constructed, to be delivered at the foot of the inclines, to be there gathered together, and the narrow wagons would be hoisted into broad gauge wagons and taken to the port. This would clearly have proved a great inconvenience, and the project of using locomotives on the 2-feet gauge, as far as the foot of the steep inclines, seemed so feasible that he gave it his warm support; and the consequence of the opposition to the broad gauge branch was, that it was withdrawn, and the project of working the narrow gauge by locomotives was carried out. He thought the attainment of a fair speed by the narrow gauge locomotive was, to a great extent, as safe as on the broad gauge, provided the wheel base were properly proportioned to the engine. With regard to the economy of the working, another question arose. As to the general principle, whether it was desirable to encourage very narrow gauge lines in positions of this kind, it depended upon the nature of the traffic. He doubted

whether that system could be extensively used for passengers; but where there was a large amount of mineral traffic coming out of narrow galleries, all going in one direction, and but a small passenger traffic going in either direction, he had no doubt a system of narrow gauge railways might be advantageously adopted. He thought it a matter worthy of legislative inquiry, whether this system might not be beneficially extended upon some well-considered gauge. At the same time, as a general principle, there was great objection to alteration of gauge. As regarded Ireland, the adoption of the gauge of 5 feet 3 inches had not produced beneficial results.

Sir CHARLES FOX remarked, that he had had a great deal to do with railways of various gauges. It was a subject to which he had given more attention than perhaps any other. He thought break of gauge was a serious matter; and yet it was difficult to say there never should be break of gauge. As joint engineer of the Indian tramway, with regard to which line a question arose as to what gauge should be adopted, he wrote a long report, in which he advised that that Company's lines should not be made tramways, but light railways; and, as in almost all cases such lines would be tributary to main lines, the gauge of which he believed was 5 feet 6 inches, he advised, that the tributary branches should be laid to the same gauge; but he coupled that advice with what, he thought, was an important condition, which was, that the load upon each pair of driving wheels of the engine to run on such lines should be limited to the greatest load that could by possibility come upon any pair of wheels in a train. He calculated 6 tons on each pair of wheels, and he did so for this reason; he considered that the tributary lines in India, if intended to pay, ought to be worked by the rolling stock of the parent lines. All the rolling stock of the parent lines, except the locomotives, might with safety be carried on rails of not more than 35lbs. to the yard, but there must be locomotives of not more than about 18 tons on three pairs of wheels, or if of 24 tons, on four pairs of wheels, thus equalising the total load by placing 6 tons on each pair of wheels. But, whether the gauge was 3 feet 6 inches, 4 feet 6 inches, or 5 feet 6 inches, the rolling stock need not be comparatively heavier in proportion to the greater width of the gauge: and if the weight were restricted to 6 tons on each pair of wheels, the light permanent way would be able to do the work. The report to which he alluded, after being considered by the Directors, was not acted upon. The line between Arconum and Conjeveram, forming a junction with the Madras main line, was of the gauge of 3 feet 6 inches; but since then, the governments of the three Presidencies came to the determination, that no tributaries to main lines should in future be of any other gauge than 5 feet 6 inches. The only condition

on which a narrower gauge was to be permitted, being where the line was not tributary to a main line; and even that, he believed, was not yet fully determined upon. His own opinion was, that the Government would adhere, in all cases, to the resolution requiring the gauge of 5 feet 6 inches. On the other hand, the objection to a uniform gauge for both main line and tributary branch was, as alleged by the managers of the companies, that they had no proper control over their servants; and that if a man was accustomed to drive an engine of 30 tons, on the main line, he could, if he chose, run the same engine on to the lighter road, very much to its injury; whereas, having a different gauge effectually prevented this being done. He thought, that there should be no separate establishment for the repair of those engines, but that all the locomotives should be the property of the parent company; the engines could then go to the same shops to be repaired, which would be a convenient and economical arrangement, particularly on a short branch. On the line to which he had referred, he had been obliged to send out all the tools necessary for the repair of the engines of 3 feet 6 inches gauge, whereas if the gauge of 5 feet 6 inches had been adopted, arrangements might have been made for the whole of the rolling stock to be repaired by the parent company, under an agreement with the branch undertaking. He thought it was more important to limit the weight on the driving wheels, than to fix any particular gauge, the latter being a matter which must be determined by the circumstances of each case. After a good deal of consideration on the subject, he thought if he had now to establish a gauge to be used all over the world, he should fix it at 5 feet 4 inches. The Irish gauge of 5 feet 3 inches was a very good gauge. The Indian gauge of 5 feet 6 inches was also a good gauge, but it necessitated a rather heavy rolling stock; while the gauge of 4 feet 8½ inches was in his opinion too narrow. At the same time, unless there was some strong reason for departing from the universal gauge of any country, he would follow out that gauge in even the light tributary lines.

With respect to Queensland, the government of that colony had decided beforehand upon making its lines on the gauge of 3 feet 6 inches, and the plans were referred to him for confirmation: more than 100 miles were now being constructed, and authority had been obtained for 200 miles more, the 'matériel' of which was now being prepared. In the case of the Indian branch of 3 feet 6 inches gauge, all the 'matériel' and rolling stock had been sent out from England, the sleepers being of teak. The line was laid upon an old road, which was granted to the Company by the Government, and which required some alterations in its curves and gradients. The total cost, including rolling stock, would be not quite £3,500 a mile.

With regard to the radiating axle boxes referred to in the Paper, and which had been adopted for sharp curves on the Norwegian lines, he was so satisfied with them that he was sending such boxes out to Queensland. He believed, that on the Queensland railway, 5 chains was the sharpest curve, and that 1 in 40 was the steepest inclination: that the weight of the rails was 40 lbs. to the yard, and that the engines with six wheels did not exceed 15 tons in steam, ready for work, exclusive of their tenders, carrying fuel and water.

The most important reason for using the narrow gauge, in this instance, was for the construction of circuitous lines through mountain ranges, where it was impossible, except at very great cost, to have curves of long radius. If it had not been for the sharp curves, he would not have recommended the narrow gauge for the Queensland lines; and it must be borne in mind, that these being the first railways in that colony, there was no existing gauge to which the gauge of these lines had to be adapted. He hoped, however, that his remarks did not lead to the supposition that he would lay down a railway, with a gauge of 5 feet 6 inches, to a slate quarry in Wales; his observations applied only to such lines as were tributary to main systems of railways.

Mr. Peter Bruff remarked, that all the Norwegian lines alluded to, were isolated. The original line, made by Mr. Stephenson and Mr. Bidder, had been extended to the confines of Sweden, and was entirely constructed on the guage of 4 feet $8\frac{1}{2}$ inches, with which the other lines of the country were never likely to be brought into communication. Radiating axle boxes, he understood, had been recently introduced on the Norwegian lines with considerable success; the weight of rails generally adopted was 37 lbs. to the yard, laid in lengths of 21 feet, the rails being flat-bottomed, $3\frac{1}{2}$ inches high, with a base of 3 inches, laid on cross sleepers, and fish-jointed. In some cases, a plated joint had been used, which, from the experience obtained in England, was not considered a desirable arrangement. Upon the subject of narrow gauge Norwegian railways, he had, however, received a communication from Mr. Pihl, who, in 1856, was intrusted by the Norwegian Government with the task of supplying railway communication between Throndhjein (about 350 miles northward of Christiania) and Storen, the point from which two main carriage roads ran south; and between Hamar, on the Lake Mjosen, about 56 English miles north of Christiania (with which it was in direct communication by rail and steamer), proceeding eastward to Eleverum, upon which the traffic of the Glommen Valley converged. Mr. Pihl stated, that he determined, from the difficulties of the country and the smallness of the traffic to be accommodated, that he should not be justified in recommending

such an outlay as would be involved by the formation of a railway as ordinarily constructed; he therefore recommended a gauge of 3 feet 6 inches. This was adopted by the Government and confirmed by the legislature (Storthing) in 1857, and shortly afterwards the works of both lines were proceeded with.

The works upon the Hamar line, being the more easy of construction, were sufficiently advanced to be used for goods traffic in the summer of 1861. The total cost of this line, for 24½ English miles, had amounted to about £3,000 per English mile. This included a large iron bridge, on stone piers, about 900 feet long, for ordinary road purposes only; the rolling stock of 3 locomotives, 6 passenger carriages, 3 break vans, and 50 goods wagons, with the necessary ballast wagons and tools for repairs; also two terminal stations, and six intermediate stations and stopping places, a carriage shed and a small repairing shop. Although the works were not of a heavy character, there were nevertheless many difficulties to contend with, the line having to ascend upwards of 400 feet, and to cross extensive and deep swamps.

The Throndhjein line of 31½ English miles, running through a difficult country, required many heavy works of construction, among which were numerous large bridges, some being from 70 feet to 100 feet high, several cuttings containing from 50,000 cubic yards to 70,000 cubic yards each, and others through rock of more than 30 feet in depth. The cost of this line was necessarily greater than the former, in all about £5,000 per English mile, including 4 engines, 8 passenger carriages, 3 break vans, 60 goods and plank wagons, beside 20 ballast trucks, with the necessary implements for repairs. There were besides the terminal stations, six intermediate stations and three stopping platforms. At Throndhjein there were also goods and carriage sheds, and a workshop for the repair of the rolling stock. This line had to cross a ridge more than 500 feet in height, in the first Norwegian mile from Throndhjein. The greater part of this distance was constructed on one side of the ridge, with gradients of 1 in 42 and 1 in 65, and on the other side of 1 in 52, the curvature being of about 900 feet radius; whereas on the other portion of the line, where the gradients were seldom more than 1 in 100, curves of 750 feet were frequently resorted to. The width at the formation level in cuttings and on embankments was 13 feet nearly; the slopes, according to circumstances, were from 1½ to 1, to 3 to 1. The ballast was 8 feet wide at the top, and 1 foot 9 inches in thickness: the sleepers were of half round pine, 6 feet 6 inches long, placed 2 feet 6 inches apart on the curves and steep gradients, and 2 feet 9 inches apart on the straighter portions of the line. The rails were flat-bottomed and fished at the joints in the usual way, 3¼ inches in height, and weighing 37 lbs. per yard, except on the steep inclines, where rails of 41 lbs. per yard were laid. The rails were

fastened to the sleepers by dog-spikes only, no bolts or bottom plates being used. Ransomes' chilled crossings, and Wild's self-acting switches were used throughout. The bridges were all of timber, except where large rivers had to be crossed, and spans of from 50 feet to 100 feet were required, in which case stone piers were carried up above flood level. The superstructure made use of in those cases was Howe's system of trellise work, with iron suspending rods. For the other bridges and viaducts a plan similar to that shown in Fig. 1, Page 374, was generally adopted, and though of light and cheap construction, it had proved very satisfactory with regard to stiffness and solidity, even at heights of more than 90 feet. The rolling stock consisted of tank engines with three pairs of wheels, two pairs being coupled for drivers, these having an available weight for traction of from 11 tons to 12 tons, out of the 14 tons to 15 tons, the total weight. The last engines procured were provided with bogies, on Bissel's or Adams' system. The cylinders were 10 inches in diameter, with a length of stroke of 18 inches, and the driving wheels were 3 feet in diameter. All the engines were made in England, with the exception of one made at Throndhjein, and were working efficiently. The passenger carriages were constructed to carry the usual number of passengers, as in England, and were arranged for two classes only, the compartments being fitted up as first and third. The goods wagons were made to carry 5 tons, and were only a few inches narrower than the ordinary kind, these widths being obtained by having the springs attached to brackets inside the sole bars, thereby allowing the lowering of the body, and in consequence, the centre of gravity. The buffers were all central, and 2 feet 6 inches above the rail level, and served also as draw-bars. The couplings on those last constructed were self-acting when the wagons were brought together. As this narrow gauge allowed a correspondingly larger wheel base than the ordinary gauge, the wagons ran very steadily. Some of the wagons were constructed to carry planks 24½ feet long, and had a length of wheel base of 13 feet.

The usual rate of speed was about 15 miles per hour, including stoppages, and the trains ran quite as steadily on this line as on the broader gauges. The traffic on these lines, though considerably below that of the lowest of the English lines, had already fully paid the working expenses, while the impulse given to the development of the resources of the country must undoubtedly, in course of time, produce a corresponding and satisfactory increase of revenue.

In order to show the economy of construction, Mr. Pihl mentioned, that simultaneously with the construction of these lines, an extension of about 50 English miles was constructed, from the old trunk line built by Messrs. Stephenson and Bidder in 1850-53

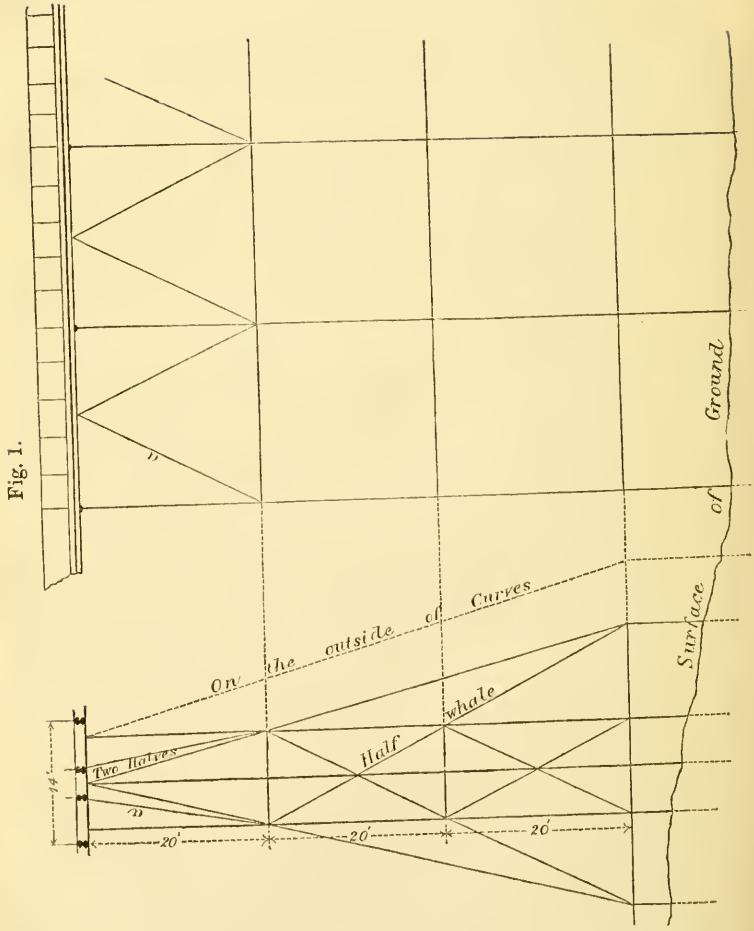

Surface of Ground
On the outside of Curves
Whole
Half
Two Halves
14'
20'
20'
20'

Fig. 1.

to the Swedish frontier, of the ordinary gauge of 4 feet 8½ inches, the cost of which was about £6,400 per English mile, the rate of wages and the class of work being, as nearly as possible, of the same description.

In addition to the two narrow gauge lines described, there was in course of construction, another line of the same gauge, between the town of Drammer and the Lake Randsfjorden, about 57 English miles in length, besides several branch lines in preparation. None of these several lines would ever have been made, had not the small cost justified and encouraged the undertakings.

Mr. Pihl added that, last summer, Mr. Charles D. Fox inspected the narrow gauge lines in Norway. All the details, with the engines and rolling stock, were unreservedly placed at his disposal; and on leaving he wrote—"With reference to the interesting question of the 3 feet 6 inch gauge, I shall return convinced of the thorough efficiency of such a gauge for the purposes of a new country, and of the wisdom of adopting such a gauge where the traffic is not very heavy."

Mr. PHIPPS inquired, whether the economy of these narrow gauge lines did not consist chiefly in the diminished cost of construction, rather than in working the traffic of the line? In his opinion, the cost of haulage per ton could not differ much, whatever the gauge might be; but as regarded the construction of the line, it would, of course, be less for the narrow way. These narrow ways were obviously suited for mountainous districts, where the curves being necessarily sharp and frequent, it became important to reduce, as much as possible, the friction arising from wheels keyed fast upon the axles, which was obviously done by diminishing the width of gauge. On tolerably level ground, with the ordinary alternations of cutting and embankment, where the slopes formed so large a proportion of the whole earthwork, the saving from narrowing the gauge would probably not be considerable.

Mr. BRUFF replied that, though considerable economy in the earthworks arose by adopting sharp and reverse curves on the Norwegian lines, the bridges and viaducts were extremely heavy, so much so, as to have astonished him when he was informed of the prices at which the lines had been carried out. No doubt, the economy of construction was greater than if a heavier rolling stock and permanent way had been employed throughout.

Mr. GREGORY, V.P., remarked that, with the narrow gauge, a shorter wheel base of the engines could be adopted, which gave greater ease in traversing sharp curves.

Mr. ROBERT MALLET said, as yet no mention had been made of another narrow gauge line, which had been a long time in successful operation, viz., that between Antwerp and Ghent, the

gauge of which, he believed, was only 2 feet 3 inches. He could not give the precise particulars of the rolling stock, but could state generally, that the carriages were wider than those on the Festiniog Railway, and that they carried heavier loads.

The subject of narrow gauge lines was not new to him. About eleven years ago he recognized the advantages, in respect of cheap railways and traffic, which would arise from narrow gauge lines; and in 1855, he had proposed to Mr. Hemans a line along the north shore of the Bay of Dublin, to have a gauge of only 2 feet 6 inches. That project, for reasons it was not necessary then to go into, was not carried out; a bill, however, was presented in the present session of Parliament for a similar line, and he hoped it might be made on the narrow gauge. In viewing the question of narrow gauge and ordinary gauge railways, it was necessary to consider, what he might call the prudential considerations, those that related to the circumstances of traffic, &c., separately from those which were of a purely physical character. He met in Sicily last year Colonel Yule, late of the Bengal Engineers, and he had had many opportunities of discussing with him what had passed relative to Indian tramways, or branch railways. Colonel Yule's opinion was decidedly in favour of narrow gauges, and he considered that in India it was simply a question between the bullock-cart, or these narrow-gauge lines, as feeders to the trunk lines. Reverting now to the purely physical considerations, it appeared to him, as a physical necessity that, not only the original cost of two similar lines differing in gauge, but also the cost of working them, would approach the ratio of the cube of the length of axle, or what was the same, of the breadth of gauge. A little consideration would show that, however startling, this proposition, without having any pretensions to be a mathematical truth, was nevertheless approximately true. As an illustration of this—if the axle of a carriage, as a cylindrical shaft, exposed to cross strains, were taken, it would not admit of dispute, that for equal strength, on different gauges, the diameter must vary as the cube of the length, or of the gauge; therefore the weight of the axles would be in that ratio, and so must be that of the wheels to carry them. Then as to the carriages, as it was equally undeniable that the weights of any similar structures whatever, varied as the cubes of their homologous dimensions, so the weight of the carriages would be as the cubes of the gauge, if the carriages were of equal lateral strength: and the axles and wheels must be proportionate to carry this load. In a word, all the rolling stock would be increased in something like the ratio of the cube of the gauge. If this were so, it followed, that the permanent way itself must be increased in a proportionate ratio to bear that load; and if it were true, that the cost of haulage was a function of the weight drawn, it equally followed,

that the rolling expenses, or those for working the line of road, would be about in proportion to this increased weight of rolling stock also. He wished to guard against being mistaken as now speaking mathematically, or as using the cube as a precise expression of the relation; his intention was merely to illustrate the proposition which he deemed generally true—that not only the first cost of construction, but also the expense of working railways, increased with the width of the gauge, but in a greatly higher ratio, or in other words, that in proportion as the gauge was reduced, both the first cost and the working expenses would be diminished. There were some special physical advantages in narrowing the gauge; for example, engines, or carriages could go round a sharp curve more easily with a 2-feet gauge than with a 7-feet gauge: this fact had had some doubt thrown on it, but its truth was obvious, from the consideration, that if the two rails could be brought close together, or into one, there would be no longer any resistance at all in going round, due to the outer wheels and inner wheels having to go over different lengths of curve in equal times.

Mr. SAVIN said, he had not at first imagined that a line of so narrow a gauge as the Festiniog Railway, could be worked successfully with locomotives; but he had travelled on that line both with locomotives and in the boat carriage, and he thought it a great success, both in regard to its adaptation to the circumstances of the locality, and in its commercial results. He agreed, that the gauge of railways in any one country should be uniform, as far as through systems of working were concerned; but, having had some experience in Wales, he thought it impracticable to carry out the broad gauge in that country. He had seen various gauges in operation, from 2 feet up to 3 feet 6 inches; his own feeling was in favour of 2 feet 3 inches, or 2 feet 6 inches, where the valleys were crooked and steep sided. In this way many physical difficulties might be avoided, by the adoption of curves of shorter radius; a 2-feet gauge line might be fitted to the contours of the hill sides, in such a manner as to reduce the cost of railway communication to a minimum. A line 16 miles long, for which he had given £20,000, was laid on the gauge of 2 feet 3 inches, and that line had been extended into a district similar to that which the Festiniog Railway passed through. There would have been very little chance of carrying a bill for a railway on a gauge of 4 feet 8½ inches in that district, and the result would have been, that but for this class of railway, the present development of the mineral resources of those valleys would not have been attained; and it was especially with reference to districts such as this, that the subject was worthy of the fullest consideration on the part of Engineers.

Mr. G. P. BIDDER, Past-President, said he had listened to the

Paper with great interest. It was an evidence that the Author, as a government official, had a view to the commercial results of railways. This system was not propounded as a measure of economy, in other respects than that there were cases in which the economy of constructing the narrow gauge should be considered, where it could be introduced, for the sake of the curves and gradients, in districts where the broader gauge could not be introduced. That was the only ground on which this question could be fairly considered; but the Author did not pretend that a narrow gauge could be worked more cheaply than a broad gauge. The arguments adduced in favour of the economy of working the narrow gauge, if followed out, would lead to the conclusion—that if there were no gauge at all, a railway could be worked for nothing. The question was, not the cost of moving a carriage, but at what cost a ton of minerals, or coals, or a hundred passengers could be moved. As a matter of practice, a ton of minerals, or a hundred passengers, could not be moved on a narrow gauge more cheaply than on a broad gauge. That it was so in this case was shown in the figures given in the Paper; for, although the substitution of steam traction in place of horses was undoubtedly a proper thing to do, yet he did not understand the Author as propounding the question of these narrow gauge railways to show that the cost of working, ton for ton, and passenger for passenger, was any cheaper than working on a broader gauge; the Author said distinctly, he did not propose this narrow gauge, except in isolated places—as in the instance given between Festiniog and Portmadoc, where the railway took the slates from the quarries to the ships, and had no connection with any other railway. But a break of gauge, whether in India, or elsewhere, was an avowed evil, and could only be reconciled by the advantages of economy of construction, as compared with the cost and inconvenience of trans-shipment. As to these railways, he had no doubt for short branches, or extensions, or even for village lines, it might be useful to introduce them. But in this country there were what were called the "Standing Orders of Parliament," which interfered very much with such lines. Engineers were allowed to deviate 5 feet vertically in open country, and were restricted to 2 feet in towns. Anything more absurd than that, it was impossible to conceive. In the neighbourhood of London, where the country was flat, a limit of 5 feet might be suitable; but in districts where the inclination of the surface of the ground was 1 in 5, or 1 in 6, the 100 yards of lateral deviation might change the work from cutting to embankment; and the 5 feet might require to be 20 feet, or 30 feet. Parliament said "A railway shall not cross a public highway in this country if it interfered with its level, excepting it be made with a gradient of 1 in 20 for a parish road and 1 in 30

for a turnpike road; nor shall it cross a road on the level, without permission." Of course, these were questions of local circumstances: 1 in 20 might be a proper gradient for London; but there were districts where the normal gradients were 1 in 7, or 1 in 10, and where the traffic might amount to three vehicles, or four vehicles per day. No attention was, however, paid to that fact, nor were reasons listened to—but a gradient of 1 in 20 was insisted on. He had had to say, on one occasion, in committee, that if such conditions were to be abided by he could not prove the preamble, for the gradient of the valley being 1 in 11, 1 in 20 would go quite across the valley. But what he proposed was, to spend £500 in improving the road on the other side of the railway, leading to the nearest village, and then the bill was passed.

With regard to level crossings, he feared he had been a great offender, for on one line he had as many as thirty-eight level crossings on as many miles of railway. But now the rule was, that there should be no level crossings. In consequence of this, where the Great Eastern Railway crossed a country road at its apex, at a most convenient place for a station, especially for minerals, the Engineer was compelled to avoid making a level crossing, though it was near the highest point of the country, and to raise that road 15 feet or 16 feet, at a cost he believed of £7,000 or £8,000. The Company could not have a station there, the opening of the line was delayed for several months, and the thing was a nuisance to the neighbourhood.

He offered these remarks, because this Paper showed, that the Author's mind was directed to commercial results. He said in effect "where the broad gauge is inappropriate have a narrow gauge." He agreed with him; but the question of commercial consideration entered as much into broad as into the narrow gauge railways, and regard must be had to the local circumstances where each gauge might be applied.

Mr. E. Woods thought it was evident, from the observations which had been made, that no one system could be laid down, nor any one gauge be fixed upon, as applicable to all conditions of locality, traffic, &c., but that each district must be treated according to its circumstances. With regard to the Indian gauge of 5 feet 6 inches, he could quite understand, it was most desirable to construct branch lines on the same gauge as the main lines, and in a flat country like India the difference of cost as between a gauge of 5 feet 6 inches and a narrower gauge would not be great, the principal item being in the additional length of the cross-sleepers. The rails might be lighter than those of the main line, and the engines for working the branches made light in proportion. Six years ago he had to construct a railway in Chili, 27 miles in length. The line was situated in the lower

range of the Andes, where the gradients were necessarily severe and the curves sharp. Here curves of 500 feet radius in combination with gradients varying from 1 in 20 to 1 in 30, constantly occurred. It was said, by the Engineers of the country, that it would be impossible to work that line with locomotives, and accordingly it was laid out for mule traffic, and it was worked by mule power for eighteen months. But owing to the seasons of drought and other causes, the expenses of working were so high, that a decision was come to by the Directors, to work the line by locomotive power. He was called upon to design the engines, and in his design he limited the weight on the driving wheels not to exceed 7½ tons, but the difficulty was to get sufficient adhesion to take the loads up the severe inclines of 1 in 20 for 7 miles, and of 1 in 30 for 12 miles. That difficulty was overcome by putting 6 driving wheels to the engines, and placing the front end on a bogie truck. The rails, of 42 lbs. to the yard, had stood exceedingly well, and up to this time were in good working order, for though the engines weighed 30 tons, the weight, being distributed over so many wheels, had produced no sensible injury to the rails. The ordinary working speed on the inclines was about 12 miles per hour.

From the experience of the working of that line, it was evident that railways of light and inexpensive construction might be advantageously worked, if due regard were paid to the adaptation of suitable rolling stock.

Mr. W. Bridges Adams said, in dealing with the question of light railways, there were two aspects from which to regard them —the commercial and the mechanical. The latter might be a toy, but the former must have reference to utility. The object being to transport materials and men, there must be sufficient volume in the carriages and wagons to hold them conveniently. Now, it was not convenient to have the dimensions so reduced as to render it necessary to strap the passengers to the seats to prevent oversetting. It was quite true, that the narrower the gauge the shorter might be the distance between the axles, if rigidly parallel, so as to facilitate passing round sharp curves; but, on the other hand, the longer the vehicle the steadier would it run, and the rigid structures which formerly needed straight lines of way, or very flat curves, might now cease to be rigid, by provision being made for the axles to radiate on curves, and point truly to the centres of those curves. By this arrangement, and by the use of spring tires, permitting the wheels to slip within the tires, it was now practicable for carriages, or engines, with extreme wheels 25 feet apart, to roll without rail friction round curves of 2 chains radius, and this fact rendered the width of gauge, whether 2 feet or 7 feet, a matter of indifference as regarded curves. On the

Norwegian line of 3 feet 6 inches gauge, engines of that class were now working.

In considering the cost of gauge, the saving could not be in the rails, but only in the length of the sleepers, and the quantity of ballast, bridges, &c. The axles might be shorter, and material might be saved in length of cross framings, but it did not follow that this was economical. With a given load, there was a certain space required to stow it, and there was a certain proportion of length to breadth of train which gave the best results in traction. A long narrow train was disadvantageous and especially so on very sharp curves. The proportion of the width of rail gauge to the width of the carriages was another consideration. As a mechanical rule, the carriage bodies might be safely made double the width of the gauge. Beyond that width there would be a tendency to unsteadiness. A 2-feet gauge, by that rule, would only admit a carriage 4 feet wide, and that, even with passengers back to back, was very cramped. Again, with passengers so placed, 3 feet in length of the carriages would only carry four passengers. While seated fore and aft, eight passengers could be carried in a 4-feet length of carriage, with a 3 feet gauge of rails, *i.e.*, one-fourth increase in length of train would double the number of passengers, or volume of goods.

With a 2-feet gauge and wheels 2 feet in diameter, the boiler and framings should be carried above the wheels altogether. With a gauge of 3 feet 6 inches, the boiler might be between the wheels; and engine-wheels of only 2 feet in diameter seriously damaged the rails if heavily loaded. If of larger diameter, better adhesion might be attained. The worst gradient on the Festiniog line appeared to be 1 in 60, but with heavier gradients heavier engines would be needed, and there was now no difficulty in constructing engines with eight drivers to roll round curves of 2 chains on any gauge. The very important feature in the engine described was the great pressure of steam—200 lbs. to the inch.

There was no doubt that narrow gauges might be made at less cost than wide ones, but it was doubtful if any material saving could be made by reducing a 3-feet gauge to a 2-feet gauge, when it was considered, that the upper structures of the train must be provided with sufficient space for convenience.

There was one reason why it was desirable to make branch lines of a narrower gauge than main lines when the traffic was light, viz., to prevent heavy engines and vehicles from running on them and destroying them. But in the coal traffic it was desirable, and possible, to employ wagons of the greatest capacity and length, capable of running round the sharpest possible curves and up to the pit's mouth, and in this case it was better to have no break of

gauge. On a gauge of 4 feet 8½ inches, it was quite practicable to use 8 wheel wagons, 40 feet long, by 9 feet wide, with an internal capacity of 1,500 cubic feet.

Mr. GREGORY, V.P., said, he was prepared to recognise the propriety of the measures adopted on the Festiniog railway, under circumstances which, he thought, were special and peculiar; but the Institution and the profession would be bold if they attempted, on the data now before them, to adopt, as had been suggested, the idea of a supplementary narrow gauge for all small branch lines. He believed that the advantage of such a gauge was limited to local conditions, such as those described in the Paper. There was an old line, having branches into several slate workings, and on account of the gauge already existing in those workings, and the character of the works and the curves of the Festiniog railway itself, it would have been exceedingly difficult to adopt the ordinary gauge; therefore the managers had endeavoured to make the most they could of an exceptionally narrow gauge, by converting the main line into a line for general goods and passengers. They also did well to introduce locomotive power on the line; but all who heard the Paper must feel that this was done under difficulties. He must record his protest against the theory, that the cost of the working expenses of railways was in proportion to the cubes of their width of gauge. The quantity of goods, or the number of passengers to be carried, was an essential element in such a question, and he thought that it might with as much correctness be affirmed that Messrs. Pickford could carry on their business more cheaply in costermongers' carts than in their usual vans. This illustration would show that such a theory could not be practically supported. He was sure while Mr. England had got work out of an engine, under difficult circumstances, with an exceptionally narrow base, that gentleman would state that he could obtain greater power, and more economy for a large amount of work, if he had a wider base to work upon.

In considering the circumstances under which an exceptionally narrow gauge might be adopted, it became necessary to investigate its supposed advantages. Setting aside the idea of any saving in working, when there was anything beyond a very limited traffic, these advantages appeared to be classed principally under two heads, viz.: firstly, a saving in cost of construction, and secondly, the easier use of sharp curves.

What had been done on the Festiniog Railway to make the most of its capabilities did not point to much saving in first cost; indeed it seemed, as had been remarked, that the saving would extend to little beyond sleepers and ballast. It was pointed out in the Paper, that to make the most of the wagon and carriage room, the rolling stock overhung so far, that a width of 4 feet 6 inches was

required between the rail and any bridge piers, and a 7 feet space between any two lines of rail; the result would be the necessity for a minimum structure width for a single line, of 11 feet, as compared with 12 feet 8 inches on the ordinary gauge, and for a double line a width of 20 feet, as compared with 23 feet 5 inches in the ordinary gauge of 4 feet 8½ inches. Such a difference would produce so small a saving in the cost of the works, as not to compensate for the disadvantages of having a very narrow wheel base, which would limit the power of the engine, and in the event of derangement of the permanent way, would cause such unsteadiness in running, that the speed common on ordinary railways would be dangerous.

With regard to curves, the friction arising from the different length of the arcs of the outer and inner rails was greater on a broad gauge than on a narrow gauge, and as rolling stock was at present generally constructed with rigidly parallel axles, the most obvious advantage of an exceptionally narrow gauge was the smaller radius of curves that might be adopted. But, he thought, modern improvements were going far to overcome the difficulties of sharp curves, and he recognised the great value of such inventions as Mr. Adams' radial axles, by the application of which to the ordinary engines and rolling stock of the country, trains might run round sharp curves on the ordinary gauge as freely as on a narrower one.

As these two supposed advantages seemed likely to disappear, he therefore concluded, that seeing the loss which took place by the uneconomical application of the power of the engine, the fact that the ordinary gauge admitted of rolling stock, which would bear a smaller proportion of dead weight to the weight carried, and last but not least the evils of a break of gauge, it might be concluded, that if there was to be an exceptionally narrow gauge in this country, it could only be advantageously applied to exceptional cases.

Mr. T. E. Harrison said, he entirely agreed, that it would be absurd to say, because this narrow gauge had been successful in its application in a particular state of things, therefore it was applicable generally. The particular case where it was applied was one in which the main traffic of the line was in slates, and the trucks were taken to where the slate was quarried, and where no large wagon could go. The slate was unavoidably brought down inclined planes in narrow wagons; and if the gauge of the main line had been broad, must have been reloaded into broad-gauge wagons. At Portmadoc the slates would have to be again transferred from the wagons to the ships alongside the quays: this narrow gauge was, therefore, unquestionably the best means of conveying them to the port of shipment. As to the mode adopted for

the conveyance of passengers, no doubt it was ingenious, and people travelled on the line with a good deal of comfort; but the works were so narrow, that when the train was standing still in a cutting, a passenger could hardly make his way past the edges of the carriages. That was not a railway which could be taken as a sample of what was desirable. It was a clever adaptation of a state of things which previously existed, and which had been designed with a different object, and as far as it went, it was exceedingly good; but to suppose that the principle upon which it was constructed was to be applied to an unlimited extent where railways of the ordinary gauge existed, was a total fallacy. It was possible that there were exceptional parts of the country where such a system might be adopted; but at the present moment such an instance did not occur to his mind. He knew there was an intention to employ the narrow gauge in other slate-quarries; but those were particular cases, and he thought, if the Institution gave its sanction, in any shape or way, to the extension of the system to general traffic, it would be leading the public in a wrong direction.

Mr. Alfred Giles remarked, that it was some years since the battle of the gauges was fought, and he had scarcely expected a fresh campaign to be opened in this Institution in favour of a 2-feet gauge.

The 7-feet gauge was known to be too wide. Mr. Hemans had observed that the Irish gauge of 5 feet 3 inches was wider than was necessary, and Sir Charles Fox had said, that if he had had his own way in India, he should have preferred to have laid the branch lines on the national gauge of this country instead of on the gauge of 3 feet 6 inches. This proved, that the old gauge was not far from the right thing. The advantages claimed for the narrow gauge were, first, great facility in traversing sharp curves; secondly, economy in construction; and, thirdly, the use of lighter rolling stock. The first two points had already been disposed of. He remembered seeing in Paris, some years ago, a little railway with a gauge of 4 feet 8½ inches running in a circle, the radius of which, he believed, was only 25 mètres. He had seen trains run round that line with great facility; and if that were so, where was the necessity for making a 2-feet gauge to save a little in the radius of the curve? It was stated that the least curve on the Festiniog line had a radius of 2 chains, or about 40 mètres. As to first cost, it had been shown that the economy could result only in a little shortening of the sleepers, and a little saving of ballast. This could not be put down at more than £300 a mile. Then as to the weight of the rolling stock, credit was claimed for the engine being only 7½ tons weight; there was no reason why an engine of similar weight (plus a little

extra for the longer axles) could not be applied to the ordinary gauge. But it had been asserted, that the weight of the rolling stock was increased as the cube of the gauge; if that were the case, the weight of the Great Western broad-gauge engines should be 343 tons. Looking at all these circumstances, it was clear that the national gauge was nearly the best that could have been chosen. On an ordinary road, where there was no limit as to gauge, carriages had a width of about 4 feet 6 inches, and even the smallest cart was wider than 2 feet; he hoped, therefore, that Engineers would not adopt the idea that the 2-feet gauge was an example to be copied, when they knew, as had been remarked, that a break of gauge was a great public inconvenience.

Mr. J. J. Allport, having had many years' practical experience in the working of railways, would offer but one observation upon this very narrow gauge. For reasons which he would state, he was of opinion that it would be most objectionable to attempt to introduce it into the country generally. With respect to the existing broad and narrow gauges, it was well known to all practical men, that the weight of a train on the narrow gauge was as great as on the broad gauge, or rather, that engines could be constructed to take as great weights on the narrow gauge as on the broad gauge; and if engines were made much heavier than at present, various difficulties, such as of wear and tear, would arise. But there was one difficulty greater than all: the principal part of the work of a train was at the stations, in the loading, unloading, and moving of trucks and carriages from one part of a station to another, across turn-tables or traversers; and any one who had had experience at a station worked upon the mixed gauge, or solely upon one or other of the gauges, must have been struck with the great additional expense in working the broad-gauge plant at the stations. It was not difficult for a couple of men to move a narrow-gauge truck or carriage to any part of the station; but to shift the broad-gauge plant, horses must be employed. The capacity of the goods wagons and coal trucks upon the narrow gauge had been gradually increased from about the size of the Newcastle chaldron of 2 tons 12 cwt. up to 8 tons, 9 tons, and 10 tons, for the load; but, he thought, all narrow-gauge managers had come to the conclusion that, from 8 tons to 9 tons for trucks was the maximum load that should be carried on the narrow gauge, with a due regard to economy and safety. If that weight for the load was exceeded, the wagon itself had to be made so much heavier, and then the friction was considerably increased, causing hot axles and other objectionable results, so that it was not uncommon to see these heavy wagons standing under their load, at various sidings and stations, and waiting to be repaired. On the Midland Railway there were

between 17,000 and 18,000 coal trucks at work; for a long time the capacity of these trucks was limited to 6 tons: now the capacity had been increased to 8 tons; but the Company did not approve of greater capacity than that. He was of opinion, that for all practical purposes the gauge of 4 feet 8½ inches was the best, and superior to either the broad, or the narrower gauge. But there was another important consideration: if a very narrow gauge were adopted, it could only be on branches connected with main lines. That would involve, in all cases, trans-shipment of passengers, goods, and coals, at the junctions; and, in itself, would cause a greater annual expense than the interest upon the increased first cost of the line upon the uniform gauge of the parent lines, both in the purchase of land, and the construction of rolling stock. That was a fatal objection to the introduction of any gauge, other than that of the line with which these branches were connected. He had no doubt that in a very few years the gauge of 4 feet 8½ inches, as being the best adapted to the commercial wants of this country, would be the only one in use.

Mr. Zerah Colburn said this Paper raised the question, how small could a locomotive be made to give practically useful work? In 1852 the contractor for a portion of the works on the Great Western Railway of Canada employed the steam excavator, which no doubt many present had seen in former days on the Eastern Counties line. For that purpose he proposed to lay the temporary line on the 3 feet 3 inches gauge, and wagons were built to hold each 15 cwt. as a load. Mr. Colburn designed and built a small 4-wheel tank engine for working those wagons, and six other similar engines were afterwards built. The tank was placed under the boiler between the frames, and as the gauge was so narrow, the fire-box was placed behind the driving-wheels, and to correct the overhanging weight, the tank was carried as far forward as possible. These engines weighed 6 tons only, with fuel and water, and could be easily taken apart, for carriage over common roads, into three principal portions, of which the heaviest weighed hardly more than 2 tons. The cylinders were 9 inches in diameter, with a length of stroke of 16 inches; and the wheels, of 3 feet diameter, were placed 4 feet 6 inches apart from the centres. The engines worked well, although of course only at moderate speeds.

Mr. James Brunlees knew the Festiniog Railway well, and though he did not question the success of working locomotives on so narrow a gauge mechanically, he much doubted its success commercially. On the other hand, he believed that, beyond a certain limit, the wider the gauge, the less would be the dividends: he looked upon that as an established fact. Some years ago he constructed a narrow-gauge line from Portmadoc to

Gorsedda, the length of which was 8 miles, and the gauge 3 feet: the total rise in the 8 miles was 900 feet, and the cost per mile, including land, was £2,000: the sharpest curve had a radius of 400 feet, and the down loads were worked entirely by gravitation; but passengers were not carried on the line; and although he had advised this line to be made on a narrow gauge, he was not prepared to recommend its further adoption, unless for exceptional purposes, or for purposes similar to the one in question. The want of uniformity of gauge was a great drawback to traffic in many parts of this country, and hence any departure from the ordinary gauge would perpetuate and augment that drawback.

Mr. GALBRAITH said, there was one principle involved in the Paper which had been lost sight of in the question of the gauges: that was—was there no room in this country, particularly in the agricultural districts, for cheaply constructed railways on the gauge of 4 feet 8½ inches? He thought there was. There were many cases where, by adopting sharp curves and a light permanent way, with light engines and level crossings at public roads, a railway might be laid down for £4,000 or £5,000 per mile, which would pay a fair dividend upon the outlay; and he hoped it would be impressed upon the members of the Board of Trade, that in respect of branch lines, on which the traffic was light, they ought to relax the stringent requirements with respect to expensive permanent way, and costly works to avoid level crossings. He had been engaged in laying out a line in Devonshire, of the character he suggested. If heavy earthworks and bridges were to be encountered, it was impossible that the line could be constructed to pay a dividend at all. In parts of Devonshire there were small public roads the traffic on which did not exceed two vehicles or three vehicles per day. To maintain, at a heavy cost, the principle of avoiding level crossings in such cases was, he thought, unwise. In many cases, railway companies erected cottages along the line for the platelayers to be near their work; and there could be no objection to the wives of the men attending to the gates at such level crossings, in consideration for living rent free. He thought curves of 10 chains or 12 chains radius, and level crossings where the public traffic was light, might be fairly admitted on branch lines, which, when constructed at £4,000 or £5,000 a mile, might be made to pay a dividend. In such cases, a light rail of 40 lbs. or 50 lbs. to the yard might be laid down, which would carry the ordinary carriages, if not the ordinary engines; but for short branches of 10 miles or 12 miles, one engine or two engines might be specially provided by the company, to work the branch alone. Such a plan as that was far preferable to an exceptionally narrow gauge causing a break between the branch and the main line, and the consequent trans-shipment of the traffic, and the supply of fresh

plant in the shape of carriages and wagons to work the traffic when so transferred. This question having been now fairly raised, he thought it was a point which ought not to be lost sight of, and which was well worthy of consideration.

Mr. Peter Barlow said, that though he was not of opinion that the gauge of 2 feet was expedient, or that any gauge at all approaching it was correct, yet, he considered, that the same gauge could not be suited to every description of traffic. The gauge adapted to the costermonger's cart would not answer for Pickford's vans, and the gauge of ocean steamers would not suit the penny boats on the Thames. He thought the cost of constructing a line was very little influenced by the width of the gauge; but was rather influenced by the width of the carriages. It was desirable that a uniform gauge should prevail all over the country, and good reasons ought to be shown for deviating from the established gauge. At the same time he hardly conceived it was a gauge suited to all circumstances, and cases might arise in which the local traffic might be better provided for by a narrower gauge. What led him to think so was the result given by the Author, who had shown that an engine weighing only $7\frac{1}{2}$ tons could take a load of 50 tons up a gradient of 1 in 60. On the Metropolitan lines, engines of 40 tons were often employed for less loads; but the exigencies of a metropolitan traffic required frequent and light trains, with power to get rapidly into speed, and thus resembled the case of the penny boats on the Thames. He agreed with Mr. Gregory, that there was little economy in the construction of these exceptional gauges, and he thought what was done upon the 2-feet gauge might possibly be done upon the gauge of 4 feet $8\frac{1}{2}$ inches. Still the fact of what had been performed by the locomotives on the Festiniog line was worthy of attention, and he thought the Institution was much indebted to the Author for having brought the subject forward.

Sir Cusack Roney had seen the gauges of Canada and the United States, and had travelled upon Continental lines in various parts of Europe. He had also had the opportunity of seeing the working of many branch lines, and he was thoroughly convinced of the desirability of a uniformity of gauge in all cases, between the branches and the main lines. He considered that the gauge adopted in this country was the correct and really practicable one. In most parts of Europe he had met with nothing but the narrow gauge: with one exception—where the line was worked by horse-power.

Mr. Robert Mallet begged to offer one or two observations in explanation. He had not intended to say, that in choosing a gauge the choice depended upon the purely physical considerations he had brought forward, but, on the contrary, that the choice of

gauge must depend upon prudential considerations, and, amongst other things, primarily upon the question of traffic. To put an obvious example: If the whole traffic were to be of cubes of granite, or other stone, each of 20 tons weight, a railway of even more than 7 feet gauge might not be sufficient. Thus at the harbour works at Holyhead the contractor's gauge was 9 feet, or 10 feet, being employed for the transport of blocks of 15 tons. But for certain conditions and amounts of traffic, a narrower gauge than 4 feet 8½ inches would not only be sufficient, but would be found the most economical and advantageous. What he had stated with reference to gauge was, that it was a general physical fact, that both the first cost of the works, and of the rolling stock of any similar railways, and also the working expenses for the haulage of any total of traffic, must increase with the width of the gauge, and as a high function of it, and that this function would probably be very nearly in the ratio of the cube of the gauges. English railways with a gauge of 7 feet, and those with a gauge of 4 feet 8½ inches, could not be compared, in those respects, not being similar either in way, or in rolling stock; thus, as respected the wheels and axles, those of the Great Western were rather lighter, being obviously weaker than those used on the narrow gauge, and having only the same width of tread. In the case of the passenger carriages, as a whole, he found the bodies were nearly of the same breadth on the narrow gauge as on the broad, on the former the overhang was greater. It was thus impossible to establish any ratio whatever between the width of gauge and rolling stock, where there was no similarity of construction on the two different gauges.

With respect to the remark that if the width of the gauge were 'nil' the cost of working would be also 'nil,' it should be remembered, that on such an assumption the traffic also became 'nil' at the same moment; so that while the mathematical deduction might be true, it did not in the least touch the question of the relative economy of the narrow and the wide gauges.

Mr. George England said, he did not for a moment apprehend, that the narrow gauge of the Festiniog railway was regarded as having been brought forward as a pattern for universal adoption. That line had been made fifteen years, and it was not originally contemplated that it would ever be worked by locomotives. During the time that the traction was performed by horses, the owners were satisfied, both with the mode of traffic and the dividend the line yielded; and it was only when another company wished to take a wider gauge into the district, that the working of so narrow a gauge by locomotive power was determined upon. It was done solely in self-defence; and he was applied to, to carry out the object of drawing a load of 25 tons up an incline of 1 in 60

at the rate of six miles per hour. The first engine that was started took a load of 50 tons up the line at the rate of 12 miles per hour. That was simply the statement that the Author had brought before the Institution. The line was 14 miles long in the incline: the wagons were taken into the slate-quarries, and the locomotive was only adopted in order to suit local circumstances.

In pursuance of the notice on the card of the Meetings, it was proposed, and resolved unanimously:—

"That in order to insure a fuller attendance of Members than could be obtained on Easter Tuesday, the Meeting be adjourned until Tuesday evening, the 25th of April."

April 25, 1865.

JOHN ROBINSON M'CLEAN, President,
in the Chair.

No. 1,110.—"On Uniform Stress in Girder Work, illustrated by reference to two Bridges recently built."[1] By CALLCOTT REILLY, Assoc. Inst. C.E.

SECTION I.—INTRODUCTION.

The general principles governing the design and construction of girders, and the merits of different classes of beams, have been so often discussed at the Meetings of the Institution, and in the works of eminent writers on engineering mechanics, that the Author feels great diffidence in bringing forward a Paper professing to deal with a special abstract principle. The general laws and the methods of their application have been settled and universally accepted, and there remains, therefore (as was well observed at the Institution two years ago) only the minutiæ of the subject of girder work, upon which any useful discussion can take place, and the Author proposes to submit some of those minutiæ, about which, apparently, a difference of opinion still exists.

In the course of a discussion[2] at the Institution in 1863, Mr. Phipps, M. Inst. C.E., suggested the importance of considering, in the design of girders, more especially of triangular truss-girders, the condition of what Professor Rankine calls "uniform stress" At the same time, he condemned the trough-shaped section, commonly adopted for the top and bottom members of truss-girders, because the intensity per square unit of the stress upon any vertical cross section is necessarily variable, when the connection of the vertical web with the trough is made in the usual manner; being greatest at the edges of the sides of the trough, and least at the outer surface of its bottom, where the mass of the material is chiefly accumulated.

The Author, in order to justify to some extent, his proposing this subject for further consideration, desires to refer briefly to the difference of opinion exhibited on that occasion. Some of the speakers, although agreeing with Mr. Phipps in principle, thought

[1] The discussion upon this Paper extended over portions of three evenings, but an abstract of the whole is given consecutively.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xxii., p. 528 et seq.

that the use of the trough was justified by its great convenience; while others, equally qualified by their experience and attainments in this department, considered the trough-shaped section was right in principle, on the ground that by its use, the greatest quantity of material is concentrated at the points where failure is most likely to begin. This opinion is probably the one most prevalent among those whose business it is to design or manufacture girder work for bridges. Convinced that Mr. Phipps's views were correct in principle, and easy of application, the Author has been allowed by Mr. Edward Woods, M. Inst. C.E., to embody his conclusions in the design of several railway bridges, now completed or in course of completion, under the direction of Mr. Woods as Engineer-in-chief; and by his permission he is enabled to submit to the Institution a description of two of these bridges, for the purpose of illustrating the application of the principle now proposed for consideration.

These bridges are of no importance as regards their magnitude or difficulty of construction. The situation and the masonry call for no special remark in either case, therefore attention is invited to the construction of the ironwork only, and chiefly to those details which were designed with the object of carrying out, as nearly as possible, in every part of the girders, the condition of uniform stress.

Before proceeding to describe these details it may be useful, in order to gain fixed ideas, to quote, as shortly as possible, Professor Rankine's definition of "uniform stress."

The words "strain" and "stress" are used indifferently in popular language to denote the same thing; but Professor Rankine, in his book on "Applied Mechanics," has adopted a distinction, which is worthy of general acceptance on the ground of perspicuity. "Stress" is there defined as a force exerted between two bodies at their surface of contact, or between two parts, into which the same body may be conceived to be divided by a plane of section passing through it in any given direction. Stress may be either a tensile force, a compressive force, or a shearing force, and is distributed over the surface of contact, or over the plane of section, as the case may be. On the other hand, the word "strain" is defined as the alteration of figure and volume of a solid body, and of its parts, produced by the action of stress as just defined. The "centre of stress" or "centre of pressure" in any surface, is the point traversed by the resultant of the whole stress, that is, the centre of parallel forces for the whole stress. If the intensity of stress per square unit of the surface on which it acts be uniform, the centre of stress must coincide with the centre of gravity of that surface; and conversely, if the centre of stress does not coincide with the centre of gravity, but deviates from it in a certain known direction, the stress is not a uniform stress,

but, under certain conditions, is called "a uniformly varying stress." Its mean intensity occurs at the axis (called the neutral axis of the stress) which traverses the centre of gravity of the surface of action; and its greatest intensity occurs at that extreme edge of the surface situated on the same side of the axis as the centre of stress, and the least intensity of the stress occurs at the extreme edge situated on the opposite side of the neutral axis.

Some apology may be due for touching upon principles so elementary and well known; but, although these principles are, no doubt, elementary, the strict proof of their existence is somewhat abstruse; and, moreover, it is only on the basis of a perfectly clear apprehension of the difference between "uniform stress" and "uniformly varying stress," that any useful argument on the present subject can be carried on.

The preceding proposition will be discussed and demonstrated in the concluding part of the Paper. The Author will, therefore, for the present, assume it to be true. Taking also as an axiom, that failure of any member of a girder, or other framework, will begin where the resistance to strain is really least, that is, where the intensity of the stress is greatest; it follows, that the opinion which upholds as right in principle the trough-shaped section as applied in the usual manner, must be a mistake. And, moreover, every form of section of any member of a girder, or framework, which does not admit of the approximate coincidence, of the centre of stress, with its centre of gravity, is liable, in degree, to the same objection.

For the sake of brevity, the Author proposes to adopt from Mr. Latham's book on "Wrought Iron Bridges," the word "boom" to denote the top and bottom members of a beam, or truss girder. Various phrases are in use for this purpose, but none appear to express so well and so concisely the functions of those members in preventing the collapse of the vertical web, somewhat as a "boom" in seafaring language, keeps stretched the sail attached to it.

The two bridges about to be described have been selected as showing different conditions of loading; No. 1 (Plates 23 and 24) carries the platform on the top, and No. 2 (Plates 25 and 26) has the platform between the main girders near the bottom. Notwithstanding that, as before remarked, the merits of different classes of trusses constitute a question, that having been so frequently discussed, is by this time somewhat threadbare, the Author hopes that he will be pardoned for reviving even this hackneyed subject, having to describe the peculiarities of two wrought-iron girder bridges which show an economy of material in the main girders, that, so far as his information enables him to judge, is not common, at least in this country. In seeking for the causes of this economy, it will be necessary briefly to compare the forms of truss chosen with other forms more usually adopted. No. 1 bridge exhibits a pair of trusses

93 feet 4 inches span between the bearings, designed to carry, in addition to the fixed load, a moving railway load of 1 ton per foot of span for a single line of way, with a maximum intensity of stress of 5 tons per square inch of tension, and $3\frac{1}{2}$ tons per square inch of compression; and the total weight of wrought iron in the frame-work of the pair of trusses is 18 tons. The cast-iron saddles rivetted on at the ends weigh $4\frac{1}{2}$ cwt. each; if these be included, the weight of iron, both wrought and cast, in the pair of trusses is under 4 cwt. per lineal foot of span.[1]

No. 2 bridge is 80 feet span between the bearings: it is designed to carry, in addition to the fixed load, a moving load of $1\frac{7}{8}$ ton per foot of single line of railway at the same maximum intensity of stress as No. 1; and the total weight of wrought iron in the pair of trusses is 20 tons 18 cwt. The cast-iron saddles rivetted on at the ends weigh $5\frac{1}{2}$ cwt. each; if these be included, the weight of iron, both wrought and cast, in the pair of trusses is 22 tons, being at the rate of $5\frac{1}{2}$ cwt. per lineal foot of span.[2] This weight is greater than that of No. 1, although the span is less, but the intensity of the assumed possible moving load is 87 per cent. greater; and the roadway lying between the trusses instead of on the top, its weight is necessarily much greater; the cross-girders are much heavier, each being adapted to support separately the heaviest load brought on by a driving axle weighted with 16 tons; the moving load thus brought upon each cross girder, and to which its strength is proportioned, is 18 tons, equal to $2\frac{1}{4}$ tons per foot of span of bridge. The trusses of No. 2 bridge have therefore a greater strength than is usual even in this country, and the preceding circumstances being borne in mind, their economy of material is even more striking than that of the trusses of No. 1.

No. 1 bridge is built to carry the single line of the "Central Argentine Railway" over the River Desmochado, or Carcarañal, about 30 miles to the westward of the town of Rosario, in the Argentine Republic. No. 2 bridge, built also for a single line of

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[1] The gross fixed load per span of this bridge is 36·16 tons, of which 22·43 tons is iron in main trusses, cross-girders, cross-girder saddles, and bracing; 11·23 tons timber and fastenings, and 2·5 tons permanent way. The above weight of iron-work is exclusive of bed-plates, rollers, &c., resting entirely on the piers. Including these items, the gross weight of iron-work, per square span, is 25·2 tons, not including bolts and spikes for fastening timber and permanent way.

[2] The gross fixed load of this bridge, per span, is 50 tons, of which 30·4 tons is iron in main trusses, cross-girders, and bracing; 10·25 tons timber and fastenings, 6·8 tons ballast, and 2·5 tons permanent way. The above weight of iron-work is exclusive of bed-plates and rollers. It is reduced to a square bridge, and the description and calculations throughout refer to a square bridge for the sake of simplicity. The actual bridge over the Wey and Arun Canal is, however, built on a very sharp angle of askew, and consequently the quantity of material actually put into that bridge is nearly 5 per cent. greater than given above, the difference being entirely in the cross-girders and platform.

way, carries the "Horsham and Guildford Railway" over the Wey and Arun Canal, in the county of Surrey, about 5 miles to the south of Guildford.

Section II.—Comparison with Ordinary Forms of Truss.

The particular form of truss chosen has not been much used in this country; it was suggested by the description, in a paper "On American Iron Bridges,"[1] by Mr. Zerah Colburn, M. Inst. C. E., read in the year 1863, of what is extensively known in the United States as the "Murphy Whipple truss;" and it was selected by Mr. Woods, after comparison with other systems, as perhaps, upon the whole, the most economical form in which the material could be arranged to obtain a given strength; and also, in the case of No. 2 bridge, because it seemed to afford the greatest facilities for a satisfactory connection with the cross girders, when, as in that bridge, the line of road passes between the trusses.

The former ground of preference, being directly at variance with influential opinions expressed during the discussion on Mr. Colburn's paper, it is proposed to explain it somewhat in detail, by means of a more exact comparison than was attempted on that occasion. Skeleton diagrams are exhibited, comparing each of the trusses selected with two equivalent trusses, of the types generally used in this country; the various circumstances of ratio of depth to span, which is as 1 : 10, and application and distribution of load, and consequently the number and position of the loaded joints, being common to the three trusses which are the subject of this comparison.

Diagram No. 1 (Plate 27) exhibits the centre lines of the various bars composing the truss adopted for No. 1 bridge, in which the struts are vertical, and the ties inclined to the horizon at 45°; Nos. 1_A and 1_B show, in the same manner, the centre lines of two equivalent trusses; the former being the ordinary Warren truss, the diagonal bars of the web being at an angle of 63° 26′ with the horizon, this angle being the one prescribed by the circumstances just mentioned. No. 1_B is the ordinary diagonal truss in its simplest form, with two sets of triangles, the bars of the web crossing at the angle of 45°.

The method of comparison adopted is that used, it will be remembered, with such excellent effect by Mr. Bramwell, M. Inst. C.E., in discussing the relative weight of material in the trusses of the various American iron bridges described in Mr. Colburn's Paper, before alluded to.

The equal loads, concentrated upon the loaded joints of the trusses, are represented by the blackened circles; the compressed bars by thick lines, and the bars subject to tension by thin lines.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxii., p. 540.

The depth of the truss is taken as the unit of length; and the unit of force and of weight is the load carried by each loaded joint. The plain figures adjacent to the bars of the web, are the several units of load vertically[1] supported by those bars, on the supposition that the whole load is fixed, and uniformly distributed among the loaded joints.

The underlined figures show the greatest number of units of load vertically carried by each bar, supposing the entire load to be a moving load of uniform intensity, travelling from one end of the truss towards the opposite end.

The plain figures written upon each of the horizontal bars of the two "booms" in each diagram, express, in terms of the unit of load, the greatest total stress upon that bar, the stress being greatest when the whole load is equally distributed among all the loaded joints: these figures, in the case of any particular bar, are therefore the sum of the horizontal components of the stresses upon those bars of the web which lie between that bar and the nearest end of the truss, and are deduced from the plain figures written upon the bars of the web. The bracketted figures will be explained hereafter. For the sake of simplifying the comparison, the intensity per square unit of the tension and compression will be assumed as equal.

From a brief consideration of these figures, the weight of each truss will now be deduced, discarding for the present all circumstances relating to the stiffening of the parts in compression, and to the practical exigencies of construction; it will be necessary, afterwards, to take some of these into account, in order to arrive at a reliable reason for preferring one truss to another.

Diagram No. 1.—The aggregate stress upon the left-hand half of the top boom, being the sum of the plain figures upon the five bars composing it, is $47\frac{1}{2}$ units,

Which . . . . × 2 ,,

Gives for the whole truss 95 ,,

And as the length of each bar is 1 unit, being equal to the depth of the truss, the weight of the top boom is proportional to the number 95.

Next as to the struts: The maximum number of units of load carried by the four and a half struts comprised in one half of the truss, being the sum of the underlined figures, is,

13·5 units,

Which . . . × 2 ,,

Gives for the whole truss 27 ,,

[1] In the case of the diagonal bars the figures represent the vertical components.

The struts being vertical, the unit of load is also the unit of stress; and as the length of each bar is unity, the weight of all the struts is proportional to the number 27. The total weight of the compressed members of the truss is therefore proportional to

$$95 + 27 = 122.$$

The aggregate stress upon one half of the lower boom, being the sum of the plain figures written thereon, is . . 35 units,

which × 2

gives for the whole truss . . 70 „

The weight of the lower boom is therefore proportional to the number 70.

The maximum number of units of load carried vertically by the diagonal ties, being the sum of the underlined figures, is for the half truss . . . . . 14·5 units,

which × 2 „

gives for both halves . . 29 „

The angle of inclination being 45°, the ratio of stress to load is $\sqrt{2}$, and the length of each tie is also $\sqrt{2}$; therefore the weight of all the ties is proportional to $29 \times 2 = 58$.

The total weight of the parts subject to tension is therefore proportional to . . . . . $70 + 58 = 128$ units,

to which add the weight in compression $= 122$ „

giving . . . . . 250 „

as the number proportional to the total theoretical weight of truss No. 1.

Diagram No. 1_A.—The same method of reasoning applied to this truss gives for the weight of

the top boom[1] . . . . 82·5 units,

of the struts[2]. . . . . 36·25 „

giving the weight of all the parts in compression proportional to ——— 118·75 units.

The weight of the lower boom[3] is also expressed by . . . 82·50 units,

and of the ties[4] by . . . 36·25 „

the whole weight in tension being proportional to . . . . ——— 118·75 „

The theoretical weight of truss No. 1_A is therefore proportional to . . . 237·5 „

[1] Thus, $(2{\cdot}25 + 6{\cdot}25 + 9{\cdot}25 + 11{\cdot}25 + 12{\cdot}25) \times 2 = 82{\cdot}5$.

[2] $(4{\cdot}5 + 3{\cdot}6 + 2{\cdot}8 + 2{\cdot}1 + 1{\cdot}5) \times 2 \times (\text{cosec.}^2 63° 26', \text{ or } 1{\cdot}25) = 36{\cdot}25$.

[3] $\left(4{\cdot}5 + 8 + 10{\cdot}5 + 12 + \frac{12{\cdot}5}{2}\right) \times 2 = 82{\cdot}5$.

[4] $(4{\cdot}5 + 3{\cdot}6 + 2{\cdot}8 + 2{\cdot}1 + 1{\cdot}5) \times 2 \times (\text{cosec.}^2 63° 26', \text{ or } 1{\cdot}25) = 36{\cdot}25$.

Diagram No. 1_B.—In this truss the proportional weight of the

top boom[1] is	80 units,	
of the struts[2]	36·8 „	
giving the weight of all the parts in compression proportional to .	———	116·8 units.
The weight of the lower boom[3] is proportional to . . .	85· units,	
that of the ties[4] to . . .	25·2 „	
The whole weight in tension is thus proportioned to	———	110 2 „
And the theoretical weight of truss No. 1_B is therefore proportional to		227 „

In this preceding comparison the weight of joints and stiffening is not included; the former may no doubt be taken as about equal for all the trusses, but the case is otherwise with the stiffening required for the parts in compression; and in trusses of much greater span and depth than those under consideration, the weight of this stiffening would be a considerable item. The Author will therefore attempt to deduce from the weight of stiffening actually put into the struts of No. 1, the comparative weights required for the other two trusses, postponing, for the present, the consideration of that required for the end pillars of No. 1_B, and for the top booms of all the trusses.

The actual aggregate weight of the transverse stiffening in the struts of No. 1 truss is 1,060 lbs.,[5] which is assumed to be the least that is possible.[6] The theoretical weight of the struts without stiffening, taking the intensity of the compressive stress at $3\frac{1}{2}$ tons per square inch, is 1,637 lbs., which, as before shown, is

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[1] $(2 + 6 + 9 + 11 + 12) \times 2 = 80$.

[2] $(2{\cdot}5 + 2 + 1{\cdot}6 + 1{\cdot}2 + 0{\cdot}9) \times 2 \times (\mathrm{cosec}^2 45°, \text{ or } 2) + 4 = 36{\cdot}8$.

[3] $(2{\cdot}5 + 6{\cdot}5 + 9{\cdot}5 + 11{\cdot}5 + 12{\cdot}5) \times 2 = 85$.

[4] $(2 + 1{\cdot}6 + 1{\cdot}2 + 0{\cdot}9 + 0{\cdot}6) \times 2 \times (\mathrm{cosec}^2 45°, \text{ or } 2) = 25{\cdot}2$.

[5] The stiffening to each strut comprises 14 diagonal bracing-bars 2 in. × $\frac{3}{8}$ in. × 1·7 foot long, and weighing 60 lbs., and 40 feet run of $1\frac{3}{4}$ in. × $\frac{1}{4}$ in. bar, being the transverse limbs of the vertical angle-irons, and weighing 58 lbs. In all 118 lbs. per strut; which, multiplied by 9 struts, gives, say 1,060 lbs. The remaining section of the 2 in. × 2 in. × $\frac{1}{4}$ in. angle-irons, is calculated as part of the compressed sides of the strut. See pp. 401 and 411, and Plate 24, Fig. 2.

[6] The possibility here is not proved; that can only be done by special experiments, which the Author has not had the opportunity of making. The bracing-bars, which contain the greater part of the material expended in stiffening the struts in the two trusses numbered 1 and 2, are considerably lighter than what are commonly used in struts of similar construction; but there is no proof that lighter ones still would have been insufficient. Moreover, the additional material required for stiffening longer struts might be more judiciously added to the compressed sides of the struts, than to the bracing-bars. Again, it may be reasonably urged that an addition to the width of the strut would be a more economical way of obtaining the desired stiffness.

proportional to 27 units of weight. The weight of the stiffening is consequently proportional to 17·4 units of weight.[1]

In order to make an exact comparison of the preceding, with the weights required for Nos. 1_A and 1_B, the following fundamental principle deduced by Mr. Lewis Gordon from Hodgkinson's experiments on long pillars[2] is quoted. "In long struts, the additional stress due to bending is to the stress due to direct pressure in a ratio which increases as the square of the proportion in which the length exceeds the diameter."[3]

From this theorem the following conclusion may, it is thought, be reasonably inferred :—"In long struts of equal width, the strength of the stiffening necessary to resist the stress due to bending, varies as the pressure upon the struts, and as the squares of their lengths." The weight of the stiffening will therefore vary as the cubes[4] of the lengths. This particular form of the question has not, it is believed, been investigated in any text book; and it is hoped, some remarks may be made during the discussion upon this subject. By the application of this principle, the proportionate weight of the transverse stiffening necessary for the struts of Nos. 1_A and 1_B, may be deduced from the known weight of that of No. 1.

First, as to No. 1_A, the sum of the vertical loads, as shown by the underlined figures, is 29 units, which multiplied by cosec. 63° 26′ or 1·118 (the proportionate length), gives 32·4 units as the sum of the pressures. The weight of stiffening in No. 1 being 1,060 lbs., and the pressures 27 units, the stiffening in 1_A : 1060 :: 32·4 : 27, and would thus be 1,272 lbs. if the struts were the same length as in No. 1. But the length being to the length in No. 1 as 1·118 : 1, the weight varies as $1{\cdot}118^3 : 1$. Therefore the weight required for No. $1_A = 1272 \times 1{\cdot}4 = 1781$ lbs. Then, as 1,060 lbs. is proportional to 17·4 units of weight, so the proportionate weight of the stiffening necessary for No. 1_A is 29·2 units, which is therefore to be added to the theoretical weight previously given.

In the case of truss No. 1_B the sum of the vertical loads carried by the struts, as shown by the underlined figures, is 16·4 units,

[1] The weight of one unit of the greatest load, both fixed and moving, this truss was calculated to support, is 6·82 tons, which multiplied by 27, the number of units of stress upon all the struts together, and divided by 3·5 tons, the intensity per square inch of the compression, gives 52·61 square inches as the aggregate sectional area of all the struts. Then 52·61 multiplied by the common length of the struts, 3¼ yards, and by 10 lbs., gives the aggregate theoretical weight at 1,637 lbs. Then, as 1637 : 27 :: 1060 : 17·4.

[2] Rankine's "Applied Mechanics," p. 361.

[3] The diameter being measured in the plane in which the bending takes place. The lateral vibration, to which the girder is liable in the transverse plane, and not in the longitudinal plane, helps to make the former the plane in which bending is most to be guarded against.

[4] The weight per unit of length being as the square, the weight per strut, being the preceding × the length varies as the cube.

which multiplied by cosec. 45 °or 1·414, the proportionate length gives 23·2 as sum of pressures. The actual weight of the stiffening in No. 1 being 1,060 lbs., and the sum of pressures 27 units, the necessary stiffening in No. 1_B : 1060 : : 23·2 : 27, and would thus be 910 lbs. if the struts were the same length as in No. 1; but the length of the struts being to those of No. 1 as 1·414 : 1, the weight varies as $1{\cdot}414^3$ to 1. Therefore the weight required : 910 : : 2·828 : 1, and thus amounts[1] to 2,573 lbs. Then, because 1,060 is proportional to 17·4 units of weight, so the proportionate weight of stiffening requisite for No. 1_B, is 42·2 units,[2] which is therefore to be added to the theoretical weight previously given.

An inspection of the plain and underlined figures, written upon the diagrams, shows that the theoretical weight of certain bars of No. 1_A, and especially so of No. 1_B, is much less than any of those in No. 1; and the question arises, Is it possible to obtain in practice the advantage of that difference? The Author believes it to be impossible in the case of several of those bars which resist compression, while admitting the possibility of doing so in the case of all the tension bars, by adopting suitable methods of jointing.

In truss No. 1, as practically worked out, there are several bars subject to compression, the scantlings of which it was found impossible to reduce to so small a size as to be proportional to the plain and underlined figures upon the diagram. For instance, the division A B of the top boom, consists of 4 angle-irons

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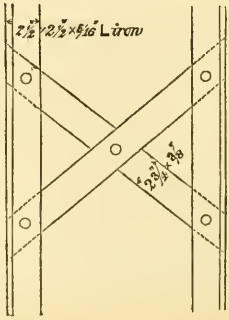
[1] $1{\cdot}414^3 = 2{\cdot}828$.

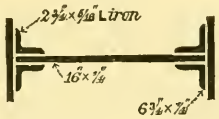
[2] To show approximately the dimensions of stiffening, similarly constructed to that of the struts of No. 1, required to give the weight of 2,573 lbs., shown to be required for truss No. 1_B. There are ten struts, averaging 257 lbs. of stiffening to each. Each strut would be about $9{\cdot}3 \times 1{\cdot}4 = 13{\cdot}7$ feet long. The weight of stiffening per foot run of strut would be $\frac{257}{13{\cdot}7} = 19$ lbs.; corresponding to the halves of four vertical angle-irons $2\frac{1}{2}$ in. × $2\frac{1}{2}$ in. × $\frac{5}{16}$ in. = 9·5 lbs., and two bracing-bars 1·4 ft. long × $2\frac{3}{4}$ in. × $\frac{3}{8}$ in. = 9·5 lbs., in all 19 lbs. per foot. (Fig. 1.) These dimensions are well known to be not greater than are generally adopted in the practice of the present time.

Fig. 1.



$2\frac{3}{4}$ in. × $2\frac{3}{4}$ in. × $\frac{5}{16}$ in., connecting together one horizontal plate 16 in. wide × $\frac{1}{4}$ in. thick, and two vertical plates $6\frac{3}{4}$ in. wide × $\frac{1}{4}$ in. thick, thus:—

Fig. 2.



It will readily be conceded that thinner plates or angle-irons could not be used with any regard to durability, and that the stiffness requisite would not admit of less width. The sectional area available for compression is $13\frac{1}{4}$ square inches,[1] whereas the area corresponding to the $4\frac{1}{2}$ units of stress marked upon the diagram is only 8·77 square inches,[2] the unit of load and stress being 6·82 tons, and the intensity of the stress $3\frac{1}{2}$ tons per square inch. This least practicable section corresponds to the 6·8 units[3] marked by bracketted figures upon the diagram, which is therefore proportionate to the least practicable weight of any bar of the top boom of No. 1; and it follows that it is also the least practicable proportionate number for 1_A and 1_B. Similarly it was found impossible to construct any vertical strut of less scantling than corresponds to 2·26 units of load,[4] on account both of the width requisite for stiffness, apart from the stiffness transverse to the length of the truss, which has been previously considered, and also to find room for the necessary rivets; and this reason would apply equally to No. 1_A and No. 1_B. It follows therefore that those underlined figures written upon the struts, which are less than 2·26 × sine-angle of obliquity, must in all three trusses be

[1] Of the horizontal plate, 16 in. × ¼ in., 13·6 in. only is available for compression, the remainder being cut away at the joints of the web.

[2] $\frac{6\cdot82 \times 4\cdot5}{3\cdot5} = 8\cdot77$ sq. inches.

[3] $\frac{13\cdot25 \text{ sq. ins.} \times 3\cdot5 \text{ tons per sq. inch.}}{\text{one unit} = 6\cdot82 \text{ tons.}} = 6\cdot8$ units.

[4] The section (shown by the shading in Fig. 3) of the lightest strut available for compression, consists of two plates 5 in. × ¼ in. = 2·5 sq. inches, and the shaded portions of four angle-irons, 2 in. × 2 in. × ¼ in. of which is available

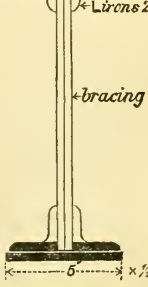
4 in. × 1·9 in. × ¼ in. = 1·9 „ „

In all . . 4·4 sq. inches.

then $\frac{4\cdot4 \text{ sq. ins.} \times 3\frac{1}{2} \text{ tons per sq. inch}}{\text{one unit} = 6\cdot82 \text{ tons.}} = 2\cdot26.$

The remaining portion of the angle-irons is not reckoned as available for compression. (See page 411.)

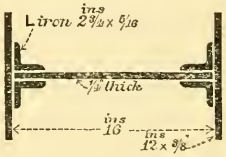
Fig. 3.



replaced by that quantity, which is accordingly marked in bracketted figures upon the diagrams.[1]

In the case of No. 1_B, the theoretical weight of the end pillars would be increased at least fivefold in the practical construction. The sectional area corresponding to the two units of load carried by the pillar is 3·9 square inches,[2] which is equal to that of a mere 4-inch angle-iron $\frac{1}{2}$ in. thick. It is inferred from observation of the lightest existing examples, that the smallest practicable section sufficient to give the requisite stiffness, and to afford room for rivets, would not be less than $19\frac{1}{2}$ square inches, corresponding to one transverse or diaphragm plate 16 in. wide × $\frac{1}{4}$ in. thick, 4 angle-irons $2\frac{3}{4}$ in. × $\frac{5}{16}$ in. and two outer plates 12 in. wide × $\frac{3}{8}$ in. thick, as shown in horizontal section in Fig. 4; and even

Fig. 4.



this section might reasonably be thought little enough. The number 2, which expresses the theoretical weight of one end pillar, must therefore be replaced by the number 10 marked thereon in bracketted figures.

The results of the preceding comparison between the three trusses will now stand as follows:—

	No. 1.	No. 1_A.	No. 1_B.
	Units.	Units.	Units.
Theoretical weight	250	237·5	227
Proportionate weight of transverse stiffening to struts.	17·4	29·2	42·2
Excess of practicable minimum over theoretical minimum, corresponding to the differences between the bracketted figures and the plain and underlined figures superseded by them[3] . .	6·18	11·5	31·6
Total weight, exclusive of joints and packings .	273·58	278·2	300·8

[1] Thus the least section of strut being such as will, at an intensity of $3\frac{1}{2}$ tons, resist 2·26 units of stress, then in truss No. 1_A,

2·26 sin. 63° 26′ or 0·894 = 2·02 units of vertical load;

and in truss No. 1_B,

2·26 sin. 45° or 0·707 = 1·6 unit of vertical load.

[2] 2 units × 6·84 tons per unit ÷ $3\frac{1}{2}$ tons intensity of stress = 3·9 sq. inches area of section.

[3] Thus, as regards No. 1;

2(6·8 − 4·5 + 2·26 − 2·1 + 1·13 − 0·5) = 6·18. [As

From this it appears that the least practicable weight of No. 1 truss is less than that of No. 1_A by 1·7 per cent. This percentage being only small, it may be said that, practically, the two trusses are equal in point of economy; there is therefore no motive for preferring one to the other, except such as may arise from considerations of workshop convenience and facility of construction; and in those respects it is submitted that, speaking generally, No. 1_A has no advantage over No. 1. The advantage, in point of economy of weight, of No. 1 over No. 1_B is more decided, being 10 per cent., sufficient, it is submitted, speaking generally and without denying that special circumstances may, in particular cases, justify a choice of the heavier truss, to entitle No. 1 to a preference over No. 1_B.

Turning now to the truss selected for No. 2 bridge, it is proposed to exhibit, as briefly as possible, the results of a similar comparison between it, and two equivalent trusses of the character commonly used under the same circumstances.

Diagram No. 2 Plate 27 shows the truss chosen for No. 2 bridge, in which the tension-bars of the web are inclined at the angle of 45°, excepting the two endmost ones, which are vertical; the two endmost struts are also inclined at 45°, but the remainder are vertical. Nos. 2_A and 2_B show two equivalent trusses, exactly similar to Nos. 1_A and 1_B respectively, excepting, that as in No. 2, the load is supported at or near the bottom. The ratio of depth to span, and the units of load and stress, and of weight, are the same relatively[1] as in No. 1.

Diagram No. 2.—The theoretical weight of the top boom, is proportional to the sum of the plain figures marked thereon × 2, thus 43 × 2 = . . . 86 units.
That of the struts, to the sum of the underlined figures, marked upon the vertical struts × 2 + 4·5 marked upon the inclined end strut[2] × 4 = 30·8 „
giving the weight of all the parts in compression proportional to . . ——— 116·8 units.

As regards No. 1_A,

$$2\{6\cdot8 - 2\cdot25 + 6\cdot8 - 6\cdot25 + (2\cdot02 - 1\cdot5)\ \mathrm{cosec.}^2\, 63^\circ\ 26'\}$$
$$= 2(5\cdot1 + 0\cdot52 \times 1\cdot25) = 11\cdot5.$$

As regards No. 1_B,

$$2\{6\cdot8 - 2 + 6\cdot8 - 6 + 10 - 2 + (1\cdot6 - 1\cdot2 + 1\cdot6 - 0\cdot9)\ \mathrm{cosec.}^2\, 45^\circ\}$$
$$= 2(13\cdot6 + 1\cdot1 \times 2) = 31\cdot8.$$

[1] The units of load, stress, and weight have the same relation as in No. 1; that is to say, they are all equal. But the absolute value of the unit is greater, being 10 tons.

[2] The factor $4 = \sqrt{2}$ for stress × $\sqrt{2}$ for length × 2 halves.

	Brought forward ..	116·8 units.
The weight of the lower boom is expressed by the sum of the plain figures marked thereon × 2, or $39\frac{1}{2} \times 2$ = ...	79 „	
That of the ties, is the sum of the underlined figures marked upon the four diagonal ties × 4 + the figure 1, upon the endmost vertical tie, × 2 = ...	42 „	
The weight of all the parts in tension is consequently proportional to .	———	121 „
Adding the weight in compression, the total theoretical weight of the truss No. 2 is proportional to . .		237·8 „

The vertical bar in the centre of the span, will be accounted for further on.

Diagram No. 2_A.—A similar calculation applied to this truss, gives the theoretical weight of the

top boom[1]	82·5 units	
of the struts[2]	36·25 „	
giving the weight of all the parts in compression, proportional to . .	———	118·75 units
The weight of the lower boom[3] is expressed by	82·5 „	
of the ties, by	36·25 „	
the whole weight in tension being thus proportional to . . .	———	118·75 „
The theoretical weight of truss No. 2_A is therefore proportional to .		237·5 „

Diagram No. 2_B (Plate 27).—The proportionate weight of the

top boom[4] is	85 units	
of the struts[5]	30·2 „	
the whole weight in compression being thus proportional to . .	———	115·2 units

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[1] Thus, $2\left(4{\cdot}5 + 8 + 10{\cdot}5 + 12 + \frac{12{\cdot}5}{2}\right) = 82{\cdot}5.$

[2] $(4{\cdot}5 + 3{\cdot}6 + 2{\cdot}8 + 2{\cdot}1 + 1{\cdot}5) \times 2 \times (\text{cosec}^2\, 63° 26', \text{ or } 1{\cdot}25) = 36{\cdot}25.$

[3] $2(2{\cdot}25 + 6{\cdot}25 + 9{\cdot}25 + 11{\cdot}25 + 12{\cdot}25) = 82{\cdot}5.$

[4] $2(2{\cdot}5 + 6{\cdot}5 + 9{\cdot}5 + 11{\cdot}5 + 12{\cdot}5) = 85.$

[5] $2\{(2 + 1{\cdot}6 + 1{\cdot}2 + 0{\cdot}9 + 0{\cdot}6)(\text{cosec}^2 45°, \text{ or } 2) + 2{\cdot}5\} = 30{\cdot}2.$

Brought forward ..		115·2 units.
The weight of the lower boom[1] is proportional to	80·0	,,
and of the ties,[2] to	32·8	,,
the whole weight in tension, being therefore proportional to . . .	———	112·8 ,,
Hence the total theoretical weight of truss No. 2_B, is proportional to .		228·0 ,,

As in the case of No. 1, it will now be necessary to proportion the weight of the transverse stiffening required for the struts, deducing the weights for Nos. 2_A and 2_B from that actually put into No. 2.

The actual aggregate weight of the transverse stiffening, put into the 6 vertical struts of No. 2, is 503 lbs.,[3] which is assumed to be the lightest possible. The theoretical weight of the same struts without joints or stiffening, is 976 lbs.;[4] taking the intensity of the compressive stress at $3\frac{1}{2}$ tons per square inch, this weight is proportional to 12·8 units. The weight of the stiffening is consequently proportional to 6·6 units,[5] which is to be added to the weight of the truss, previously given.

Next as to No. 2_A; the two endmost struts A L and K V will be considered apart, as, like the end struts of No. 2, involving a different construction to the others. The sum of the vertical loads, as shown by the underlined figures upon the remaining eight struts, is 20 units,[6] which, multiplied by cosec. 63° 26′ or 1·118 (the proportionate length), gives 22·4 as sum of pressures. The weight of stiffening in No. 2, being 503 lbs., and pressures 12·8 units, the stiffening in No. 2_A : 503 : : 22·4 : 12·8 and would thus be 880 lbs. if the struts were the same proportionate length as in No. 2.

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[1] $2(2 + 6 + 9 + 11 + 12) = 80$.

[2] $2(2{\cdot}5 + 2 + 1{\cdot}6 + 1{\cdot}2 + 0{\cdot}9)$ (cosec.^{2} 45°, or 2) = 32·8.

[3] Made up thus:—there are actually sixteen bracing-bars to each strut, about 2 ft. 3 in. × $1\frac{3}{4}$ in. × $\frac{5}{16}$ in., each weighing 4 lbs.; to which must be added two pairs, or four bars, of the same weight, to replace the two plates to which the cross-girders are attached, which mode of fastening is inapplicable to Nos. 2_A and 2_B. There is also to be added half the weight of the four short bars, or two pairs, at the top of each strut. Then $\left(4 \text{ lbs.} \times 20 + \frac{4 \times 1{\cdot}9 \text{ lbs.}}{2}\right) 6 = 503$ lbs.

[4] The aggregate number of units of stress to be supported by the six vertical struts is $(2{\cdot}8 + 2{\cdot}1 + 1{\cdot}5)\,2 = 12{\cdot}8$. The unit being 10 tons, and the intensity 3·5 tons per sq. inch, the aggregate cross section is $\frac{12{\cdot}8 \times 10}{3{\cdot}5} = 36{\cdot}6$ sq. inches.

The aggregate weight is therefore 366 lbs. per yard, and the mean length being $2\frac{3}{4}$ yards, the total theoretical weight is 976 lbs., which is therefore proportional to 12·8 units of weight, the unit of stress and of weight being the same as before mentioned.

[5] 976 : 12·8 : : 503 : 6·6.

[6] $2(3{\cdot}6 + 2{\cdot}8 + 2{\cdot}1 + 1{\cdot}5) = 20$.

But the length being to that in No. 2, as 1·118 : 1, the weight varies as $1{\cdot}118^3$ to 1. Therefore the weight required = 880 × 1·4 = 1232 lbs.; and as 503 lbs. is proportional to 6·6 units, so the proportionate weight of transverse stiffening required for No. 2_A, is 16·1 units of weight,[1] which is therefore to be added to the theoretical weight previously given.

As to No. 2_B, the sum of the vertical loads carried by the 10 diagonal struts, as shown by the underlined figures, is 12·6 units,[2] which, multiplied by cosec. 45° or 1·414 (the proportionate length), gives 17·8 as the sum of pressures. The actual weight of stiffening in No. 2 being 503 lbs., and the pressures 12·8 units, the weight of stiffening in No. 2_B : 503 : : 17·8 : 12·8, and would thus be 700 lbs. if the struts were the same proportionate length as in No. 2. But the length being to that in No. 2 as 1·414 to 1, the weight varies as $1{\cdot}414^3$ to 1; hence the weight required = 700 × 2·828 = 1979 lbs.;[3] and as 503 lbs. is proportional to 6·6 units, so the proportionate weight of the transverse stiffening required for No. 2_B, is 26 units of weight,[4] which is therefore to be added to the theoretical weight previously given.

As in the trusses numbered 1, so there are in the present cases several bars subject to compression, which it would be found impossible or inexpedient, to fine down to the small dimensions, proportional to the plain and underlined figures upon the diagrams.

In truss No. 2 (Plate 26), each of the vertical struts, consists of 4 angle-irons 3 in. × 3 in. × $\frac{3}{8}$ in. Smaller bars would not afford room for the necessary rivets required to carry out the condition of uniform stress; and for the same reasons it follows that smaller dimensions would be equally inadmissible[5] in trusses No. 2_A and No. 2_B.

The sectional area of the strut, the whole of which is available for compression, is 8·4 square inches;[6] the unit of stress (that is the load upon each joint of the truss), being 10 tons, and the intensity of the stress $3\frac{1}{2}$ tons per square inch, this area corresponds to 2·94 units of stress,[7] which multiplied by the sine of the obliquity

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[1] 503 : 6·6 : : 1232 : 16·1.

[2] 2 (2 + 1·6 + 1·2 + 0·9 + 0·6) = 12·6.

[3] $1{\cdot}414^3 = 2{\cdot}828$.

[4] 503 : 6·6 : : 1979 : 26.

[5] It may be objected, that a lighter form of strut might be devised for Nos. 2_A and 2_B, because that peculiar form was dictated more by the nature of the cross-girder attachment than by its function as a strut; and that cross-girder attachment is inapplicable to 2_A and 2_B, owing to their struts being inclined. But whatever form of strut and cross-girder attachment could be devised for those two trusses, the same could be adopted for No. 2, and therefore the results of the present comparison would not be materially affected.

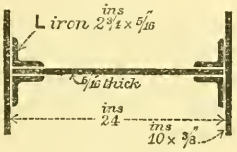
[6] Sectional area of one angle-iron 3 × $\frac{3}{8}$ = 2·1 sq. inches; 2·1 × 4 = 8·4 sq. inches.

[7] $\frac{8{\cdot}4 \times 3{\cdot}5}{10}$ = 2·94 units. In explanation of the reason why the least practicable weight in units of the struts in No. 2 is greater than in No. 1, although the [struts

gives the number marked by bracketted figures[1] upon the diagrams, and must be considered as replacing, in all the three trusses, those underlined figures which are less than itself. The central vertical bar in No. 2, does not belong to the system of struts and ties ; its use is to prevent the deflection of the top boom between D and F, and as it is also constructed to receive the fastening of the middle cross girder, it is made of the same strength and stiffened in the same manner as the vertical struts, and its weight is consequently proportional to the number 4·04 written upon it in bracketted figures, which is made up of the before-mentioned 2·94 units, + 1·1 unit, the equivalent[2] of its transverse stiffening.

The least practicable section for the inclined end struts, required to give sufficient lateral stiffness to the truss, was considered to be 21·48 square inches, made up thus, as shown by Fig. 5.

Fig. 5.



One transverse plate 24 in. wide × $\frac{5}{16}$ths thick, 4 angle-irons $2\frac{3}{4}$ in. × $2\frac{3}{4}$ in. × $\frac{5}{16}$, in. and two side plates 10 in. wide × $\frac{3}{8}$ in. thick, the total sectional area being 21·48 sq. in. At $3\frac{1}{2}$ tons per square inch, this section is equivalent to 5·3 units of load,[3] which number is accordingly marked in bracketted figures upon the diagram, and must replace the plain and underlined figures in the ultimate calculation.

For the reason just given the least practicable section for the end strut of No. 2_A, would be the same as that used for No. 2, namely

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struts are shorter, it may be stated that the entire section, in the former case, is rendered available for resisting the compression, by reason of the peculiar mode of attachment to the ties and booms. (See page 411.) This mode of attachment could not well be applied with lighter angle-irons. As a set-off against this expenditure of material, less is required for stiffening, owing to the stiffness inherent in the shape of the angle-iron, and also to the circumstance that the line of action of the resultant of the compression intersects the centre of gravity of each angle-iron. Whereas, in No. 1, slightly more than half only of the section of the angle-irons is reckoned as available for compression, because the compression is not communicated directly by the rivets to the remainder, which, however, is accounted for in the calculations as part of the stiffening. See foot-note [4], page 401.

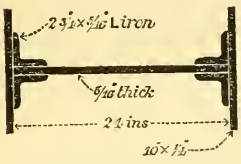
[1] Thus, in No. 2_A, 2·94 × sin. 63° 26′, or 0·8944 = 2·63.
and in No. 2_B, 2·94 × sin. 45°, or 0·7071 = 2·1.

[2] The actual weight of this stiffening is 84 lbs.;
then, as 503 lbs. : 6·6 units :: 84 : 1·1.

[3] $\frac{21{\cdot}48 \times 3{\cdot}5 \times \text{sin. } 45° \text{ or } 0{\cdot}707}{10 \text{ tons per unit}} = 5{\cdot}3.$

21·48 square inches. This section is equivalent to 6·72 units[1] of vertical load, which number is accordingly marked in bracketted figures upon the diagram No. 2_A. The lightest bar A B of the top boom of this truss could not, it may be reasonably assumed, have a less section than 18·18 square inches, made up of one horizontal plate 24 in. × $\frac{5}{16}$ in., of which $21\frac{1}{2}$ in. in width would be available in compression, four angle-irons $2\frac{3}{4}$ in. × $\frac{5}{16}$ in. and 2 plates 10 in. × $\frac{1}{4}$ in.

Fig. 6.



At $3\frac{1}{2}$ tons per square inch, this section will resist a compression of 63·63 tons, equal to 6·36 units, which number is accordingly marked in bracketted figures upon the diagram. This number is also marked upon the lightest bar A B, of the top boom of truss No. 2_B, as being proportional to the weight of the lightest section practicable in that case. In that truss the theoretical weight of the vertical pillar at the end is proportional to $2\frac{1}{2}$ units of stress and weight, whereas the lightest pillar practicable to give the requisite stiffness and durability, would be equivalent to 6·65 units,[2] which is the number marked in bracketted figures upon the diagram. The section would be that shown by the last figure, and would consist of one transverse plate 24 in. × $\frac{5}{16}$ in., 4 angle-irons $2\frac{3}{4}$ in. × $\frac{5}{16}$ in., and two side plates 10 in. × $\frac{1}{4}$, the total sectional area being 19 square inches.

The final comparison between the three trusses will now be as follows:—

	No. 2.	No. 2_A.	No. 2_B.
	Units.	Units.	Units.
Proportionate theoretical weight	237·8	237·5	228·0
Proportionate weight of stiffening to struts. . .	6·6	16·1	26·0
Weight proportionate to the excess of practicable minimum over theoretical minimum, corresponding to the differences between the bracketted figures and the plain and underlined figures, superseded by them[3]	12·08	13·42	32·82
Proportionate total weight, exclusive of joints and packings	256·48	267·02	286·82

[1] $\frac{21{\cdot}48 \times 3{\cdot}5 \text{ tons per sq. inch} \times \sin 63° 26' \text{ or } 0{\cdot}894}{10 \text{ tons per unit}} = 6{\cdot}72.$

[2] $\frac{19 \times 3{\cdot}5 \text{ tons per sq. inch}}{10 \text{ tons per unit}} = 6{\cdot}65.$

[3] Thus as regards No. 2:—

$$2\left\{(5{\cdot}3 - 4{\cdot}5)\operatorname{cosec.}^2 45° + 2{\cdot}94 - 2{\cdot}8 + 2{\cdot}94 - 2{\cdot}1 + 2{\cdot}94 - 1{\cdot}5 + \frac{4{\cdot}04}{2}\right\}$$
$$= 2(1{\cdot}6 + 0{\cdot}14 + 0{\cdot}84 + 1{\cdot}44 + 2{\cdot}02) = 12{\cdot}08.$$

[As

It thus appears that No. 2 truss is lighter than either of its competitors, and that No. 2_B is much the heaviest of the three. The percentage in favour of No. 2, as compared with No. 2_A, is 4·15 per cent., and, as compared with No. 2_B, 11·87 per cent.

From these comparisons it would appear that American engineers, who have extensively adopted the form of truss which is the type of Nos. 1 and 2, have in this matter displayed the usual acuteness of their nation, and deserved more credit than was awarded them in the discussion on Mr. Colburn's Paper[1] two years ago.

Section 3.—Peculiarities of Detail.

The Author will now proceed to describe the peculiarities of detail in the two bridges, passing over, as not affecting the present subject, those features which resemble ordinary constructions of this kind.

Beginning with the method by which the load is transmitted from the cross girders to the main trusses, it is suggested that this has an important bearing upon the subject of uniform stress. It will be noticed that the trusses of both bridges have a double web, that is, the web is divided into two distinct halves, one on the inner side of the truss and one upon the outer side; and these two halves have no other connection with each other than is given by the light transverse stiffening bars, which are applied only to the struts, and to those ties which alternately act as struts, under the influence of the travelling load. This construction is of course perfectly well known, and is that usually applied in trusses of considerable span. In order that the stress may be uniformly distributed over the surface of any cross section of either boom, it is in the first place necessary that the two halves of the double web should each support, exactly, one half the load upon the truss. It is submitted that by the ordinary modes of fixing the cross girders this important condition cannot be realized; whether the cross girder rests upon the flat surface of the top boom, or is rivetted to the inner vertical side of a trough-shaped lower boom, or whether it is suspended from the latter by bolts or stirrup-irons applied to both sides of the lower boom, or, as is not so common, to one side only. In all these cases when the cross girder deflects,

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As regards No. 2_A :—

$$2\{6\cdot36 - 4\cdot5 + (6\cdot72 - 4\cdot5 + 2\cdot63 - 2\cdot1 + 2\cdot63 - 1\cdot5)\ \mathrm{cosec.}^2\,63^\circ\,26'\}$$
$$= 2\{1\cdot86 + (2\cdot22 + 0\cdot53 + 1\cdot13)\,1\cdot25\} = 13\cdot42.$$

And as regards No. 2_B :—

$$2\{6\cdot36 - 2\cdot5 + 6\cdot65 - 2\cdot5 + (2\cdot1 - 2 + 2\cdot1 - 1\cdot6 + 2\cdot1 - 1\cdot2 + 2\cdot1 - 0\cdot9 + 2\cdot1 - 0\cdot6)\ \mathrm{cosec.}^2\,45^\circ\}$$
$$= 2\{3\cdot86 + 4\cdot15 + (0\cdot1 + 0\cdot5 + 0\cdot9 + 1\cdot2 + 1\cdot5)\,2\} = 32\cdot82.$$

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxii.

whether the amount of deflection be appreciable or not, the entire load will be carried by the fastenings or supports upon the inner side of the truss, and consequently, by the inner half of the web, and the outer half, both of the web and of the booms, will be doing little more than resisting the stress caused by their own weight.

In the two bridges under consideration this effect is obviated and the condition of uniform stress realised, by supporting the cross girders in the middle of the width of the truss. In No. 1 bridge each cross girder rests upon a light cast-iron saddle or bridge, which spans the width of the top boom, and has its bearing partly upon the top edges of the vertical struts, and partly upon rivets passing through the struts and the vertical side-plates of the top boom. The cross girder has its bearing upon a raised fillet, cast upon the middle of the top side of the saddle, and shaped very slightly convex upwards (Plate 24, Figs. 1, and 5 to 12). In this way the line of action of the vertical force transmitted from the cross girder to the truss, coincides exactly with the vertical centre line of its width. The bottom edge of the saddle is raised sufficiently clear of the horizontal plate of the top boom to allow water to drain off from the centre of the span towards the ends of the truss, the camber of which affords sufficient inclination for that purpose.

In No. 2 bridge, as the roadway passes between the trusses near the bottom, a different arrangement was necessary. Each vertical strut consists of two pairs of vertical angle-irons, each 3 in. $\times$ 3 in. $\times$ $\frac{3}{8}$ in. thick, as shown in horizontal section in Plate 26, the two of each pair being connected together by the transverse stiffening-bars, each $1\frac{3}{4}$ in. $\times$ $\frac{5}{16}$ in., crossing each other diagonally.

The two pairs of angle-irons are separated, in the plane of the truss, by a space just sufficiently wide to permit the end of the cross girder to pass in between the pairs. At the same level as the cross girder a plate, 12 in. deep $\times$ $\frac{1}{2}$ in. thick, is rivetted to each pair of angle-irons; these two plates constitute a pair of small beams, which bridge over the width between the two angle-irons of each pair; and in the centre of that width the end of the cross girder is rivetted to each plate by a cluster of eight rivets, placed as close together as possible. (Plate 26.) Thus the weight, transmitted by the cross girder to the truss, is equally divided between the four vertical angle-irons which constitute each vertical strut, and the resulting stress is thereby equally distributed between the two halves of the web, and, consequently, between the two halves of either boom. The same mode of attaching the cross girders is applied to the vertical ties, and to the central vertical bar, severally marked on the diagram of No. 2 truss

(Plate 27), as A L, J T, and E P. A single-turned pin or bolt might perhaps have been substituted for each of the groups of rivets before mentioned with some advantage.

In both bridges the centre lines of the vertical struts, the diagonal ties, and the top and bottom booms, intersect each other at the centre of gravity of the group of rivets which attaches each strut and tie to the boom (Plate 24, Fig. 4); and, in order to satisfy the condition of uniform stress, it is necessary that these centre lines should intersect the centre of gravity of every cross section of each strut, tie, and boom; and in these two bridges this result is attained by making all the centre lines axes of symmetry. The struts in No. 1 bridge (Plate 24, Figs. 2 and 3) do not differ materially from a very common form of construction, each consisting of a pair of flat bars, each bar stiffened on the inner side by a pair of light angle-irons, between which the stiffening lattice-bars are rivetted. One side only of each of these angle-irons, that lying in the plane of the truss, is reckoned as of *pro ratâ* value with the flat bars in resisting compression, the other limb of the angle-iron being considered only as stiffening, because it is only to the former that the stress is directly communicated by the rivetting. A flat junction-plate (Plate 26) is rivetted to the top and bottom of each bar, wide enough and thick enough to receive the proper number of, and give sufficient bearing to, the rivets at the top and bottom joints. At the bottom of the strut this junction-plate is lengthened in the plane of the truss for a reason that will afterwards appear. With respect to No. 2 bridge, it has been already stated that each vertical strut consists of two pairs of vertical angle-irons; the two of each pair stiffened, in the plane at right angles to the plane of the truss, by a system of light diagonal bracing of flat bars. These four angle-irons are placed symmetrically with respect to the vertical centre-line of the strut, and they are connected (two and two) to the top and bottom joints by junction-plates of a proper size to receive the number of rivets required, and to give them sufficient bearing. These junction-plates are so contrived as to divide the stress, not only between the four angle-irons equally, but also equally between the two sides of each angle-iron, giving an equal amount of rivet-bearing upon each side. Moreover, the centre lines of the rivets all intersect the centre of gravity of the cross section of each angle-iron. (Plate 26.)

The diagonal ties of the web are simple flat bars or plates. In No. 1 bridge the two marked E Q, Q G, diagram No. 1, are stiffened, transversely to the plane of the truss, by the same kind of lattice-work as is applied to the struts; because in those ties, as is well known, the greatest compression produced by the travelling load exceeds the tension produced by the fixed load. For

the same reason in No. 2 bridge the four ties marked C O, D P, P F, Q G, are stiffened in a similar manner.

The condition of axial symmetry, by which the centres of gravity of the web-joints are made to coincide with the centres of gravity of the booms, is attained, in both bridges, by making the lower boom of two chains of plates, placed with their sides vertical. The plates constituting each chain are rivetted together, not only at the web-joints, but also continuously between them, in order to exclude the atmosphere from the inner surfaces, a mode of construction which has been often adopted. In the top booms of both bridges a section has been adopted which is believed to be new, and to present some peculiar advantages (Plate 24, Figs. 14 and 15). It is somewhat like a capital letter H, elongated in the horizontal direction, or like a common plate-girder placed upon its side. The horizontal plate or diaphragm of the boom is no thicker than is necessary to give it sufficient lateral stiffness; each longitudinal edge of this horizontal plate is connected to one or more vertical plates by a pair of angle-irons, and the additional strength required towards the centre of the span is obtained by adding more of these vertical plates. The advantages of this kind of section are, that all its centre lines are axes of symmetry, and consequently intersect each other in its centre of gravity, and the horizontal axes are easily made to intersect the centres of gravity of the web joints. The chief mass of metal is also placed immediately contiguous to the bars of the web, which transfer the stress to the boom, instead of being at some distance from them, as in the trough-shaped and T-shaped form of boom. A collateral advantage is, that the material is disposed in the best possible manner for resisting vibration. This section has also a further advantage over the box-shaped section (which is otherwise a good one when made symmetrical) in giving complete facilities for examination and painting. The drainage of rain-water from the upper surface is effected by giving the truss considerable camber, which allows the water to flow out at the ends of the boom; and to prevent corrosion from this cause, the upper surface of the horizontal plate or diaphragm is coated smoothly with asphalte up to the level of the rivet-heads.

The ends of each truss rest upon hinged bearings, by means of cast-iron saddles rivetted to the junction of the endmost bars of the truss, rollers being provided at one end. (Plate 23.) This system of hinged bearings has been previously used in this country, but more frequently on the continent; and it is thought that there are good reasons to justify its universal adoption in all girders consisting of open framework, and even in plate girders of large span.

The means adopted in the design of these girders, to obtain the utmost economy of weight consistently with moderate economy of workmanship were, the closest practicable approximation of the average strength to the minimum strength, the observance throughout of the condition of uniform stress, in order that all the compressed members might be trusted with the least possible weight of stiffening, the preference of rivetted web-joints to those formed by single pins, and such an arrangement of the rivetting, that every bar or plate subject to tension should have its whole width, less the diameter of only one rivet-hole, available to resist the tensile force applied to it. In order to carry out this last condition, at the points where the bars of the web join the lower boom, the junction-plates before spoken of as being applied to the lower ends of the struts are elongated so as to take up, rivet by rivet, part of the stress upon the boom before it arrives at the joint, and to give it out again in the same manner upon the opposite side of the joint. Thus the section along any line of rivets is sufficient to give, at the least, the minimum strength required.

The maximum limits of the tensile and compressive stress have been already stated. The strength of the rivetting is regulated by the condition that the pressure upon the rivet-bearing shall not exceed 5 tons per square inch, and that the intensity of the shearing stress upon the section of any rivet shall also not exceed the same limit.

It is now proposed to demonstrate, by comparison, the detrimental effect of unequally distributed stress.

Section 4.—Comparison with a trough-shaped Boom.

In order to illustrate the true value of the condition of uniform stress in its relation to the construction of girders, an exact comparison will now be attempted of the state of the bar D E, of the top boom of truss No. 2 (diagram No. 2), when under uniform stress, with that condition of unequally distributed stress, that would occur, if the boom had a suitable trough-shaped section of equal area, and therefore equal nominal value.

That this may be done in a complete and comprehensive manner, an exact demonstration will be given of what appears to be the best method of calculation, applicable to this object.

In Professor Rankine's admirable work on "Applied Mechanics," the effect and mode of action of unequally distributed stress are investigated; but the reasoning is so completely generalised (as indeed it should be in a work of that nature), in order to include all possible cases, that many of the steps are unavoidably complicated, and troublesome to follow. By confining the investigation to a specific practical instance, some of the considerations which

complicate the perfectly general solution will be eliminated, and a simplification, which it is hoped may be useful, will result.

It is therefore proposed to adapt this general method to the specific instance of a trough-shaped boom, of definite form and dimensions, and capable of comparison with the form of boom adopted for one of the trusses previously described.

Let Fig. 3, Plate 27, represent the section of a top boom, having the trough shape, the interior depth being the same as the extreme depth of the boom of No. 2 truss, and having the same sectional area. And let the figure A B C D, Fig. 4, represent in isometrical projection, the same trough-shaped cross section; the plane of section being at right angles to the longitudinal line, joining the centres of gravity of the top joints of the web of the truss, and situated at a sensibly small distance from the nearest of those joints. A B is the top, and A D and B C the sides of the trough, C and D being its lower corners. Let O be the centre of gravity of this plane of section; – Y O Y, – X O X, a pair of rectangular axes of co-ordinates traversing O, as origin, in the plane of section, and parallel, respectively, to A B and C B; and, – Z O Z, an axis perpendicular to that plane.

Case 1.—Stress uniform in Intensity.

It is necessary, in the first place, to exhibit an exact solution of this case, because some of the mathematical expressions involved in it, are also involved in the solution of the case of stress unequally distributed, to be afterwards considered.

Let it be supposed, then, that the centres of gravity of the several joints, which connect the bars of the web with the top boom, lie in the axis – Z O Z, supposed for that purpose to be indefinitely continued. It is evident that the stress upon the plane of section, is entirely produced by the forces applied to the top boom by the diagonal bars of the web, being the sum of the horizontal components of the diagonal stresses upon those bars, whose top joints lie between the plane and the nearest end of the truss. Then because the centre of gravity of each of those applied forces lies in the axis O Z, the direction of the stress upon the plane of section must be wholly normal, and its resultant act in the direction of O Z, cutting the plane in its centre of gravity. It is therefore the resultant of a system of equal parallel forces, distributed uniformly over the surface of section; and O, the centre of gravity of the surface, coincides with the "centre of stress," or the "centre of pressure," as defined in section 1.

So far as concerns the stress upon the surface A B C D, the trough will then be in a condition similar to that of a vertical pillar of the same figure of cross section, compressed in the direction of

its vertical axis of gravity[1] O Z, by a load which is correctly represented by the weight of an imaginary parallel—ended prismatic solid, A C F E, whose base coincides with the surface of section, and whose uniform height, C F, is proportional to the intensity of that load. The direction of the applied force being supposed downwards or negative, that of the stress which resists it is upward and therefore positive.

Let P = the amount, or magnitude, of the resultant of the stress.
p_o = its intensity per square unit of the surface of section,
V = the volume of the solid A F,
w = its weight per unit of volume,
S = the area in square units of the surface A B C D.

Then from the preceding argument, $P = w \cdot V = p_o \cdot S$; p_o being a constant quantity, because the height C F, of the solid is uniform.

Hence the preceding is a case of uniform stress, and requires no further remark, except this important one,—that in order to produce this condition of the stress, it is necessary not only that the centre of gravity of each web joint shall lie in the plane Z O Y, but also in Z O X. To effect this result, it is absolutely necessary that some such method of attaching the cross girders, be adopted as has been described in section 3. The details of such an attachment would not necessarily be the same as there described. It is obvious that many variations of detail are admissible in different circumstances; but it is essential that the effect shall be, to divide the load equally between the two lateral divisions of the web.

Case 2.—Stress unequally Distributed.

It is now proposed to investigate that condition, of unequal distribution of the stress, upon the plane of section, A B C D, of the trough, which is produced, when, as is generally the case in practice, the longitudinal line joining the centres of gravity of the web joints, traverses the plane of section at a point R, whose perpendicular distance below O Y is O R; R being thus the "centre of stress" as defined in section 1. As the solution is much simplified, by supposing the point R, to lie somewhere in the axis − X O X, and as the result will then be that most favourable to the cause of the trough-shaped boom, it will be assumed that some mode of attaching the cross girders is adopted, equivalent to that just alluded to, which will effect that object. Supposing the amount of the diagonal forces acting through the bars of the web, and also the area S, of

[1] "Axis of gravity," a short phrase signifying the line intersecting the centres of gravity of every plane cross section of the boom, or pillar.

the plane of section to remain the same as in case 1, the magnitude P, of the resultant of the stress upon that plane, will remain the same as in that case. The direction of the resultant, and also of all the parallel components, of the stress upon the plane will remain the same, that is to say, normal to the plane, its position being close to one of the web joints, and it being assumed[1] that no sensible flexure of the boom can at that point take place, which would affect the direction of the stress with respect to the surface of section.

Having fixed the preceding data, it will now be evident that the trough is in a similar condition to that of a vertical pillar compressed by a load – P, which will be correctly represented by the weight of an imaginary prismatic solid. A B C D S H T G, (Fig. 4, Plate 27), whose base coincides with the surface of section, and whose specific gravity and volume are the same as in case 1; but whose perpendicular height z, at any point in the surface of section, varies in proportion to the intensity of the stress at that point. The essential object of the present investigation is to find a method of calculating the relative values of z, and particularly its greatest and least values.

For the sake of brevity, the parallel ended solid, A C F E, will be called No. 1 solid, as belonging especially to case 1; and the new solid A B C D H S G T, will be distinguished as solid No. 2. It must be distinctly remembered, that the weights, and consequently the volumes of the two solids, are exactly equal; and as they stand upon the same base, the difference between them is only in height; C F, that of No. 1, being uniform, and the height of No. 2 varying from B T to C H, according to a law depending upon the distance O R, and upon the perfection, or imperfection, of the elasticity of the material subjected to the action of the stress. As is usual in all similar investigations, it is assumed that Hooke's law of perfect elasticity is sensibly true for wrought iron,[2] the material generally employed in structures of this kind.

The centre of gravity of solid No. 2, will necessarily lie somewhere in the line, R R′, drawn parallel to O Z; R R′ is therefore the line of action of the resultant, – P, of the set of parallel forces

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[1] This assumption may possibly be questioned in the case of a plane of section so near the centre of the span of the girder. But whether true or not in such a case, it is undoubtedly true when the plane of section is situated near to one of the endmost joints; for instance, the joint A in the bay A B. And if the ratio $\frac{P}{S}$ be not less in that instance than in the former (as it manifestly should not be), then the detriment to the strength of the structure will be as great as if the assumption in the text were unquestionably true. Generally the detrimental effect will be proportionate to the absolute value of that ratio, other things being equal.

[2] See note [1], page 421.

acting vertically (the boom being considered as if it were a vertical pillar), which compose the weight of No. 2 solid.[1]

As the magnitude, P, of the total stress is the same as in case 1, its *mean* intensity to be denoted by p_o, in the present case will be the same as the uniform intensity in case 1. Consequently there will be a line in the surface of section A B C D, for which the ordinate, z, of No. 2 solid, will = C F, the height of solid No. 1. This being so, the entire stress upon the section may be considered as made up of two parts, viz. :—

First, a uniform stress, whose intensity is the mean intensity of the entire stress, and whose centre is the centre of gravity, O, of the surface of section A B C D. As in case 1, this mean intensity is $p_o = \frac{P}{S} = \frac{\text{total stress}}{\text{area}}$. Secondly, a varying stress, whose amount is nothing, and which is therefore positive and negative (or compressive and tensile), on the opposite sides of some neutral axis traversing the plane of section. The intensity, p', of this second part of the stress, at any point in the surface, is the deviation of the total intensity at that point from the mean; so that the total intensity at any given point, is expressed by the equation $p = p_o + p'$.

On the assumption that Hooke's law is sensibly true, the varying stress just spoken of, is "an uniformly varying stress;" that is, a stress whose intensity, at a given point of the surface to which it is applied, is proportional to the distance of that point from the neutral axis which will be proved to traverse the centre of gravity, O, of the surface of action.

This composition of the entire stress is represented in the diagram, Fig. 4, Plate 27, by the solid No. 2, being considered as made up of—the parallel ended solid No. 1, shown in outlines, representing the uniform stress P, plus the shaded wedge-shaped solids, F H*k*, and N S*n*, and minus the shaded wedge-shaped solid *kn* J T E G, which together represent the uniformly varying stress whose amount is nothing.[2]

As the first part of the stress, represented by the solid No. 1, has been already determined, it now remains to find the resultant of the second part of the stress; the value and effect of this resultant depending upon the volume and figure of the shaded double wedged-shaped solid, N S F H E T. The shortest method of solving this part of the problem, is by the process of integration.

In the plane E J F N, assume a new pair of rectangular axes, – Y' O' Y', – X' O' X', parallel to, and in the same vertical

[1] Because R R' coincides with the line of action of the resultant of the applied forces brought on to the plane of section by the pull upon the diagonal bars of the web.

[2] It should be observed that – P is the weight of the solid acting in a downward direction, while + P is the equal and opposite stress acting upward.

planes as the original axes. It is evident, that the moments of any element, of the second part of the stress, with respect to the new axes, will give precisely the same result, as affecting the surface of section, as if reckoned with respect to the original axes. The object of the change of axes, being merely, to make the geometrical representation by means of the diagram, consistent with the algebraic symbols employed.

Consider the surface E J F N, whose area is S (being the same as A B C D), to be composed of an infinite number of infinitesimally small rectangular elements, the area of each being denoted by the differential $d\,x\,d\,y$, and the stress upon each by $p'\cdot d\,x\,d\,y$.

Let the axis of co-ordinates — Y′ O′ Y′ be for the present assumed (as will afterwards be proved) to be the neutral axis of the stress; x is then the perpendicular distance of any one element from this neutral axis. By the definition of "a uniformly varying stress," previously quoted, the equation $p' = a\,x$, or $a = \frac{p'}{x}$ (a being a constant), represents the law of variation of the uniformly varying stress.[1] Then, because the ratio a is constant, the inclined surface, H S T G, is a plane surface; and the ordinate, z, proceeding from any element of the plane surface, E J F N, to that inclined plane, will be proportional to the intensity, p', of the stress upon that element, and will indicate, by its upward or downward direction, whether that stress is positive or negative; and the nullity of the whole varying stress will be indicated by the equality of the volumes of the positive wedges F H k, N S n, to that of the negative wedge $k\,n$ J T E G. Then, because the amount of the stress upon the plane E J F N is nothing, its resultant is a couple whose moment to be denoted by M, and the position of its axis, which must necessarily[2] be the neutral axis of the total stress, is to be found as follows:—w, as before being the uniform weight per unit of volume of the solids, the stress acting upon each rectangular element is

$$w\,z\cdot d\,x\,d\,y = p'\,d\,x\,d\,y = a\cdot x\,d\,x\,d\,y,$$

because $p' = a\,x$. The moment of that stress round O′ Y′ is

$$x\,w\,z\cdot d\,x\,d\,y = a\cdot x^2\,d\,x\,d\,y,$$

and is right-handed or positive, looking from + Y′ towards O′, and round O′ X′ is

$$y\,w\,z\cdot d\,x\,d\,y = a\cdot x\,y\,d\,x\,d\,y,$$

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[1] This law requires the ratio $p' : x$ to be a constant ratio; whereas, if the variable stress was not uniformly varying, a would not be constant; a is therefore the intensity, per unit of area, of the stress at the distance unity from the neutral axis.

[2] "Necessarily," because the first part of the stress being of uniform intensity, and having, therefore, no neutral axis, the neutral axis of the second part of the stress, that is, the axis of the couple, must be the neutral axis of the whole stress.

which is right or left-handed, looking from + X′ towards O′, according as the element is situated on one or the other side of − X′ O′ X′. Summing and integrating these elementary moments, the total moments of the partial resultant couples are found,

$$\text{round O′ Y′ to be } M_y = a \cdot \iint x^2 \, dx \, dy,$$
$$\text{round O′ X′ to be } M_x = a \cdot \iint x \, y \, dx \, dy.$$

Then, as is well known, the moment of the resultant couple will be

$$M = \sqrt{(M_x^2 + M_y^2)}.$$

But because the figure E J F N, that is, the section of the trough, is symmetrical round the axis − X′ O′ X′, which contains the point R′, then for every point at which y has a given positive value there is a corresponding point for which it has an equal negative value; so that in the present case, the integral

$$\iint x y \cdot dx \, dy = 0.$$

Hence M_x vanishes, and the moment of the resultant couple is simply

$$M = a \cdot \iint x^2 \cdot dx \, dy = a \, I,$$

which is, in fact, merely the constant, a, multiplied into the well-known expression for the moment of inertia of the surface E J F N, that is, A B C D, taken with respect to the assumed neutral axis O′ Y′. It now remains to prove the truth of that assumption thus. The partial resultant couples relative to the rectangular axes being respectively M_x and M_y, it is well known that the angle θ which the axis of the resultant couple makes with O′ X′ is to be found by the equation

$$\cos \theta = \frac{M_x}{M}.$$

In the present case M_x vanishes, therefore cos θ vanishes, θ is a right angle, and hence the axis of the couple coincides with − Y′ O′ Y′, which must also traverse the centre of gravity of the section for the following reason. The resultant of the second part of the stress being a couple, the magnitude of the stress is nothing, and is expressed by

$$\iint p' \, dx \, dy = 0;$$

but because $p' = a \, x$, in which a is constant and x variable,

$$\iint p' \, dx \, dy = a \cdot \iint x \, dx \, dy = 0,$$
$$\text{and therefore } \iint x \, dx \, dy = 0.$$

Let x_0 be the co-ordinate, relative to − Y′ O′ Y′, of the centre of gravity of the surface; then the well-known general equation of x_0, for the centre of gravity of *any* plane surface, relative to *any* rectangular axis of y, gives

$$x_0 = \frac{\iint x \, dx \, dy}{\iint dx \, dy}.$$

But $\int\int d\,x\,d\,y$ is the area of the surface, and has the magnitude S; therefore x_0 must be nothing, and hence the neutral axis, $-$ Y′ O′ Y′, must traverse the centre of gravity of the surface E J F N, as was previously assumed.[1]

It is thus proved that the total stress upon the original plane, A B C D, is resolved into a force, P, which is the magnitude of the entire stress upon that plane, applied at its centre of gravity O, and acting in the direction O Z, + a right-handed[2] couple, whose moment is $M = a\,I$, whose tendency is to turn the plane, E J F N, round the axis O′ Y′, elevating the edges, F N, and depressing the opposite edge, E J, until they coincide respectively with H S and G T. As is well known, the effect of such a combination of a single force with a right-handed couple, is to shift the line of action of the resultant, P, parallel to itself, in a direction perpendicular to the neutral axis, O Y, and to the left of O (looking from + Y towards O), through a distance

$$L = \frac{M}{P} = \frac{a\,I}{P};$$

L being thus the arm of the couple M, and equal to O R, the perpendicular distance of the line of action of the resultant of the applied force, $-$ P (which alone produces the stress, and is equal and opposite to P), from the neutral axis $-$ Y O Y.

Substituting, in the last equation, for the constant a its value as previously determined, the equation

$$\frac{p'}{x}\,I = L\,P$$

is deduced, which is an equation of moments from which may be computed the intensity p' of the second part of the stress at any point whose perpendicular distance from O Y is x. That is to say,

$$p' = \frac{x\,L\,P}{I},$$

which being added to p_0, the uniform intensity of the first part of the stress, that is, the mean intensity, $\frac{P}{S}$, gives the total intensity of the stress at that point, observing, of course, the positive or negative signs of p' and x, p_0 being considered positive.

[1] If R, instead of being situated in the plane Z O X, had been situated at any distance to one side or the other of that plane, the neutral axis of the stress would still intersect O′, the centre of gravity of the surface, and would make an angle θ with $-$ X′ O′ X′ to be determined by the equation $\cos\theta = \frac{M_x}{M}$, M_x in such a case having a value to be obtained by solving the equation for M_x given in the text.—(See Rankine's "Applied Mechanics," arts. 91 to 95.)

[2] "Right-handed," when it is viewed by an observer, looking from + Y towards O, his head being in the direction of + Z.

This final result is denoted by the equation

$$p = p^{\circ} \pm \frac{x \, \mathrm{L} \, \mathrm{P}}{\mathrm{I}}.$$

Applying this formula to the case of the trough-shaped section of boom, shown in Fig. 3, Plate 27, which is a section supposed to be equivalent to the H-shaped section actually used for the division D E of the top boom of truss No. 2, the following results are obtained. The trough is supposed to have the following dimensions: the top plate is $\frac{5}{8}$ in. thick and about 2 ft. $2\frac{1}{8}$ in. wide, connected by two angle-irons $2\frac{3}{4}$ in. $\times$ $2\frac{3}{4}$ in. $\times$ $\frac{5}{8}$ in. to the two sides, supposed each to be 10 in. wide $\times$ $\frac{11}{16}$ in. thick. It is submitted that this arrangement of the material is not unfavourable to the cause of the trough-shaped section, because there are many actual instances where the sectional area of the top bears a greater proportion to that of the vertical sides than in this example. The area of section is 36·17 square inches, exactly equal to that in No. 2 truss. The inside depth of the trough being 10 inches, will permit exactly the same disposition of the rivets in the web-joint; so that the centre of pressure, R, is situated at the same perpendicular distance, viz., 5 inches, from the lower edges of the trough as from the lower edges of the H-shaped section actually used. The centre of gravity, O, is found to be situated at 8·088 inches perpendicular distance from the lower edge of the trough, and 2·537 inches from the top edge, L being therefore 3·088 inches. The magnitude of the total stress upon the section is P = 125 tons. The uniform intensity of this stress is $p_o = 3{\cdot}45$ tons per square inch, and the moment of inertia with respect to the axis, O Y, is $\mathrm{I} = 336{\cdot}902$. The extreme values of x are

$$-x = 8{\cdot}088 \text{ inches, and } x = 2{\cdot}537 \text{ inches.}$$

From these data the greatest stress is found to be at the edges C and D, and

$$= p = 12{\cdot}717 \text{ tons per square inch,}$$

the least intensity occurring at the edge A B, and being

$$= p = 0{\cdot}544 \text{ tons per square inch.}^{1}$$

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[1] The numerical details of this calculation are given at length in the Appendix. Comparing the proportions of the trough-shaped section in Fig. 3, Plate 27, with those of many existing instances, it would appear that the inequality and greatest intensity of the stress calculated by the formula, on the supposition of perfect elasticity, must in existing bridges often exceed that attributed to the example. Therefore the question naturally arises, Why are not frequent break-downs or, at all events, serious crippling, heard of as arising from this cause? In reply to this question, the Author wishes to suggest, that possibly the imperfect elasticity of the material, which is very properly considered to be a defect, is, in fact, the salvation of those structures. This suggestion may be illustrated by reference to the diagram Fig. 4, Plate 27, in this way. When the material at the edge, C and D, suffers by

Anything like this enormous inequality in the stress, shown to exist in such examples as the preceding, ought not to be permitted, and it is submitted that this subject, minute and highly refined as it appears to be, is worthy of attentive consideration; and the Author hopes that a full discussion and criticism of the preceding argument will eliminate whatever errors it may contain, and will result in the further establishment, upon a firmer and wider basis, of sound principles in this department of construction.

In summing up the conclusions which the Author has sought to establish, he submits that—

First, A comparatively small deviation of the centre of stress upon the cross section of any bar, of any piece of framework, from the centre of gravity of that section, produces, within the limits of elasticity, a comparatively great inequality in the distribution of the stress upon that section.

Secondly, If it be conceded that the real strength of every structure is inversely proportional to the greatest strain suffered by its

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the application of the test-load, a strain exceeding the limit of elasticity (which occurs when the strain exceeds about 11 or 12 tons per square inch), it takes a permanent set, which remains after the load is removed. The effect of this permanent set is known to be,* that a reapplication of the load producing the same stress would produce a less proportionate strain, or alteration of figure, than at first; so that Hooke's law, which states that the strain is proportional to the stress, would no longer apply. The oblique plane surface H S G T, whose inclination represents to the eye the action of that law, would, at the point whose z co-ordinate, measured by the scale, represents the limit of elasticity, cease to be plane, and would become curved and concave downward as it approaches H S, thereby shortening the ordinate F H or N S, and consequently diminishing the volume of the positive wedge-shaped solids H F k and S N n. But in order to maintain the equality of volume of the positive and negative wedges, which is necessary, to make the resultant of the second part of the stress nothing, an equal diminution in the volume of the wedge G E J T $k n$ would ensue. But because the intensity of the stress on that part of the section lying between the neutral axis and the edge A B is far within the limit of elasticity, the oblique surface between $k n$ and T G must remain a plane surface, and therefore the diminution in the volume of the negative wedge would necessarily involve a shifting of the neutral axis out of the centre of gravity, and towards R, together with a shortening of the negative ordinates J T and E G. The immediate effect of this would be a redistribution of the stress upon the plane of section, increasing its intensity at the edge A B, and diminishing it at C D. In the preceding remarks the author must not be understood as even suggesting that the elastic limit may be safely exceeded either in iron or any other material. He merely suggests that, in the precise kind of case selected for illustration, the permanent set produced, *at one edge only*, by such excess, caused by the proof load, occasions a shifting of the neutral axis, and a consequent redistribution of the stress due to the reapplication of a load less than the proof load.

There is no doubt that the formula in the text gives correct results, under the assigned conditions, up to a maximum limit of stress, whether tension or compression, of 11 or 12 tons per square inch; but to give correct results beyond that limit, the formula would require the introduction of a term expressing the law of variation of the proportion between the strain and the stress, when the latter exceeds that limit. The value of such a term can only be deduced from a carefully-performed set of experiments, specially directed to that object.

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* *Vide* Fairbairn's "Useful Information for Engineers." Second Series, p. 125, where details are given of some experiments at Woolwich, whose results support this view.

weakest member, then the existence of this unequal distribution of the stress must be detrimental to the strength of any structure in which it exists, and which has been designed on the supposition that the mean intensity of the stress upon any bar is necessarily a correct measure of its strength.

Thirdly, There is no practical or theoretical difficulty, in designing a truss or girder, in which the stress upon every cross section, of all the important members at all events, shall be absolutely uniform.

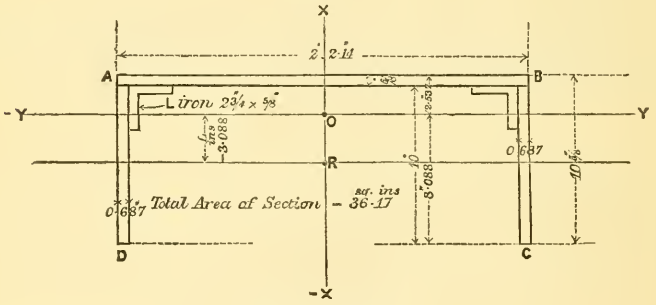
Fourthly, The condition of uniform stress is perfectly consistent with the utmost economy of material in the structure to which it is applied.

The Paper is illustrated by numerous drawings and diagrams, from which Plates 23, 24, 25, 26, and 27, and woodcuts, Figs. 1 to 8, have been compiled.

APPENDIX.

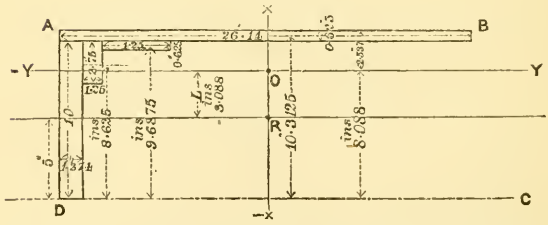
Application of the formula, $p = p_o \pm \frac{x L P}{I}$, to find the greatest and least values of p on the section, Figs. 7 and 8, where the line of action of the resultant intersects the plane of section at a point, R, whose perpendicular distance below the horizontal axis – Y O Y intersecting the centre of gravity, O, of the surface, is L, the point R lying in the vertical axis – X O X.

Fig. 7.



Section of Trough.

Fig. 8.



Equivalent Section arranged in the form most convenient for the calculation.

To find height of – Y O Y above lower edge C D; that is, to find position of neutral axis of section.

		Inches.	Inches.	Sq. Ins.		Sq. Ins. × Ins.
No. 1.	Area rect.	10	× 1·374 =	13·74,	moment = 13·74 × 5	= 68·70
No. 2.	„ „	2·75	× 1·25 =	3·44,	„ = 3·44 × 8·625	= 29·67
No. 3.	„ „	4·25	× ·625 =	2·65,	„ = 2·65 × 9·6875	= 25·67
No. 4.	„ „	26·14	× ·625 =	16·34,	„ = 16·34 × 10·3125	= 168·50
			Sum of areas =	36·17	Sum of moments	292·54

Then $\frac{292 \cdot 54}{36 \cdot 17} = 8 \cdot 088$ inches = height of – Y O Y above C D.

Hence L = 8·08 — 5 = 3·088 inches.

Computation of I *with respect to* − Y O Y.

Dimensions of each rectangle are, parallel to x, side = h, parallel to y, side = c; distance of its centre from O Y = $x_\circ$.

Then $I = \Sigma \cdot \frac{h^3 c}{12} + \Sigma \cdot h c x_\circ^2$.

No.	$x_\circ =$	$x_\circ^2 =$	$h c x_\circ^2 =$
1	$-8{\cdot}088 + 5{\cdot} = -3{\cdot}088$	9·536	$13{\cdot}74 \times 9{\cdot}536 = 131{\cdot}025$
2	$8{\cdot}625 - 8{\cdot}088 = 0{\cdot}537$	·288	$3{\cdot}44 \times 0{\cdot}288 = 0{\cdot}991$
3	$9{\cdot}6875 - 8{\cdot}088 = 1{\cdot}600$	2·560	$2{\cdot}65 \times 2{\cdot}56 = 6{\cdot}784$
4	$10{\cdot}3125 - 8{\cdot}088 = 2{\cdot}224$	4·946	$16{\cdot}34 \times 4{\cdot}946 = 80{\cdot}818$
			$\Sigma \cdot h c x_\circ^2 = 219{\cdot}618$

	$h^3 c = h^2 h c =$
1	$(10^2 = 100) \times 13{\cdot}74 = 1374{\cdot}00$
2	$(2{\cdot}75^2 = 7{\cdot}56) \times 3{\cdot}44 = 26{\cdot}01$
3	$(0{\cdot}625^2 = 0{\cdot}39) \times 2{\cdot}65 = 1{\cdot}03$
4	$(0{\cdot}625^2 = 0{\cdot}39) \times 16{\cdot}34 = 6{\cdot}37$
	$\Sigma \cdot h^3 c = 1407{\cdot}41$

$$\Sigma \cdot \frac{h^3 c}{12} = \frac{1407{\cdot}41}{12} = 117{\cdot}284$$

Therefore $I = 336{\cdot}902$

The extreme values of x are,

$-x = -8{\cdot}088$ inches, $\quad x = 2{\cdot}537$ inches,

$L = -3{\cdot}088$ „

$P = 125$ tons;

$$\therefore \quad p' = \frac{-x(-L)P}{I}$$

$$= \frac{-8{\cdot}088 \times -3{\cdot}088 \times 125}{336{\cdot}902} = 9{\cdot}267 \text{ tons per sq. inch,}$$

and $$-p' = \frac{x(-L)P}{I}$$

$$= \frac{2{\cdot}537 \times -3{\cdot}088 \times 125}{336{\cdot}902} = -2{\cdot}906 \quad „ \quad „ \quad „$$

Also $$p_\circ = \frac{P}{S} = \frac{125}{36{\cdot}17} = 3{\cdot}45 \quad „ \quad „ \quad „$$

Therefore, at the edges C and D of the trough,

$$p = p_\circ + p' = 3{\cdot}45 + 9{\cdot}267 = 12{\cdot}717 \quad „ \quad „ \quad „$$

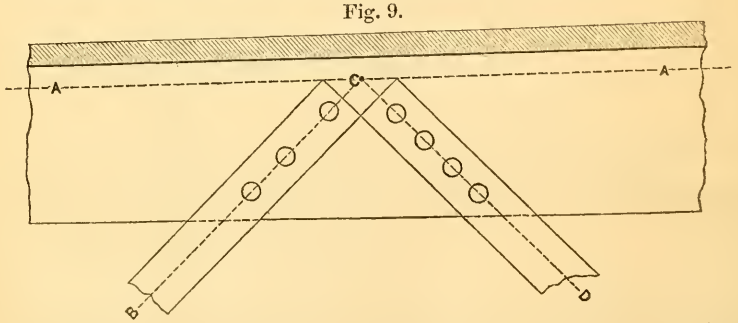
and at the edge A B, $p = p_\circ - p' = 3{\cdot}45 - 2{\cdot}906$

$= 0{\cdot}544$ tons per sq. inch.

Mr. Reilly said, that he did not bring forward these bridges as examples of perfect construction; on the contrary, he had little doubt forms could be devised which would more perfectly fulfil the conditions contended for; but he thought that Engineers would consider the subject an important one, and on that account these examples would, perhaps, be of some interest. The ironwork of No. 1 bridge was manufactured at the Canada Works, Birkenhead. All the rivet holes at the web joints were drilled, and the edges of all the plates were planed. The price for the wrought iron was £17. 7*s*. 6*d*. per ton, and for cast iron, all of which was more or less machined, £14. 10*s*. No. 2 bridge was manufactured by Messrs. James Taylor and Co., at the price of £18. 10*s*. for wrought iron, and £14 for cast iron, in both cases delivered free on board, or at the railway station. At the time the latter contract was taken, iron bars were about 30*s*. per ton higher than they were at present.

He did not desire to be understood as condemning the trough form of section unconditionally. He thought it might be reasonably contended, that the trough might be made partially to fulfil the condition of uniform stress, providing the joints of the web bars, with the trough, were designed with that object, which, however, had not yet been attempted, so far as he was aware. Of course, it was impossible to make the centre of pressure of a joint coincide with the centre of gravity of the section of the trough; but, probably, the desired result might be effected, to a certain extent, by so adjusting the position of the bars of the web, that their axes of gravity produced, should intersect the axis of gravity of the trough in the same point, somewhat as shown in Fig. 9:

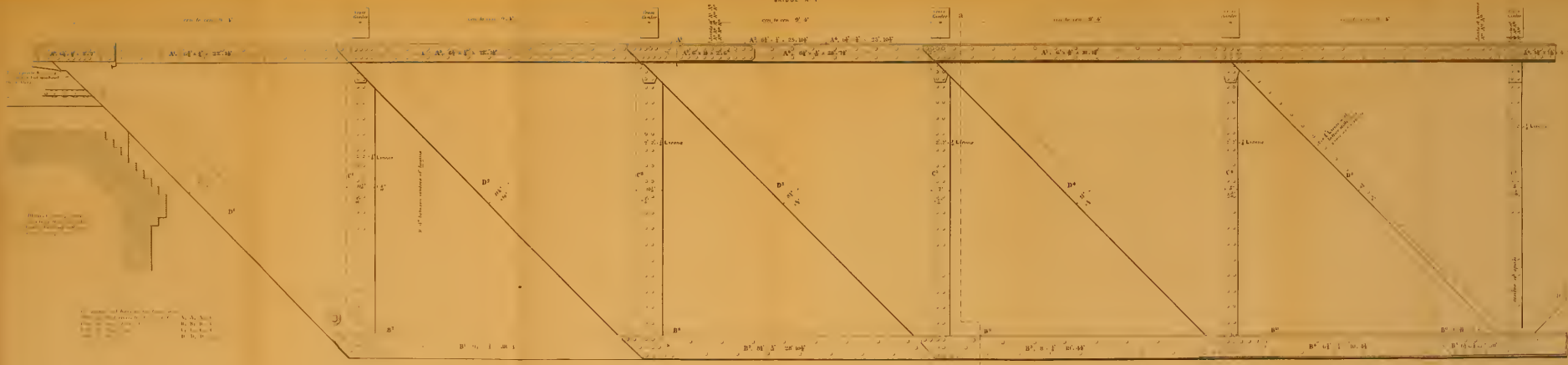
Fig. 9.



If the bars were made to meet in that way, it would seem indifferent, so far as regarded the question of uniform stress upon the boom, how the rivets or pins were placed. But it would be necessary to give sufficient extra strength to the sides of the trough, in the triangular space between the web bars and immediately

UNIFORM STRESS IN GIRDER WORK.

BRIDGE N° 1



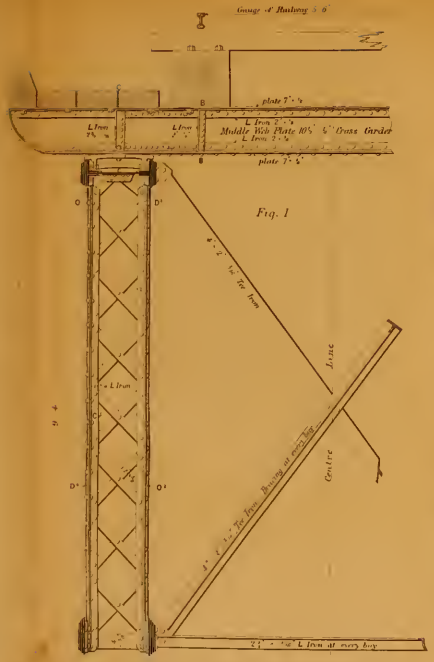
HALF ELEVATION OF MAIN GIRDER

HALF HORIZONTAL SECTION THROUGH CENTRE OF LOWER BOOM.

HALF CROSS SECTION OF PLATFORM

UNIFORM STRESS IN GIRDER WORK.

BRIDGE N°1 DETAILS

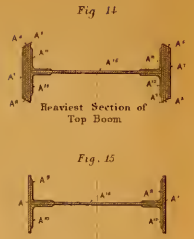

Gauge of Railway 3' 6"
plate 7" × ½
Middle Web Plate 10½" × ⅝" Cross Girder
L Iron 2" × ½
plate 7" × ½
Fig. 1.
Centre
Centre to Centre of Main Girders 9' 0"

Cross Section of Main Girder through A B on Elevation

Side View of Strut C³

The other Struts differ only in the width of Plate

End View of Strut C³

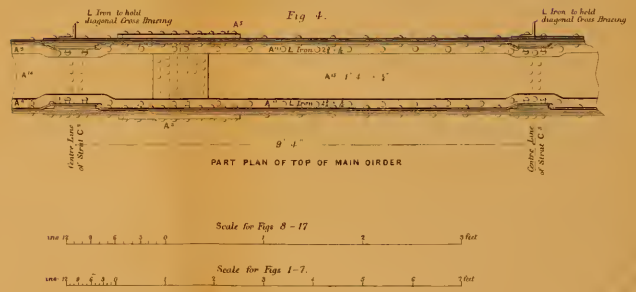


Heaviest Section of Top Boom

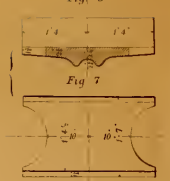
Heaviest Section of Bottom Boom

Lightest Section of Top Boom

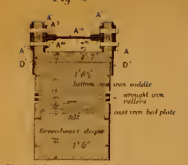
Lightest Section of Bottom Boom


L Iron to hold Diagonal Cross Bracing
Fig 4.
L Iron to hold Diagonal Cross Bracing
9' 4"
Centre Line of Strut C³
Centre Line of Strut C³

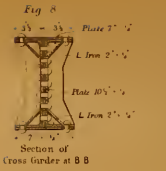
PART PLAN OF TOP OF MAIN GIRDER



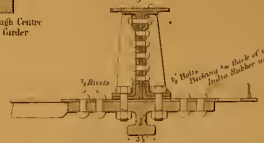
Top Cast Iron Saddle at ends of Main Girder



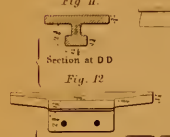
Vertical Section through Centre of Bearing of Main Girder



Section of Cross Girder at B B



Section of Cross Girder and Saddle at C C showing attachment of Horizontal Bracing

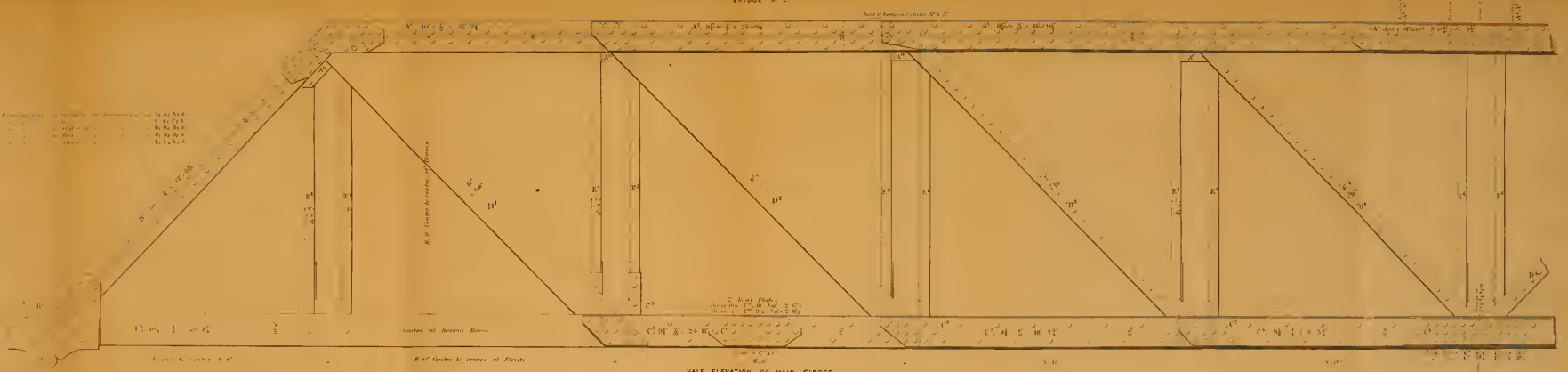


Plan and Elevations of Cross Girder Saddle

Ends of Horizontal Cross Bracing Bars, shown dotted

UNIFORM STRESS IN GIRDER WORK.

BRIDGE N° 2.



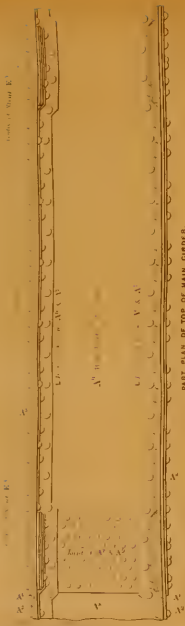
HALF ELEVATION OF MAIN GIRDER.

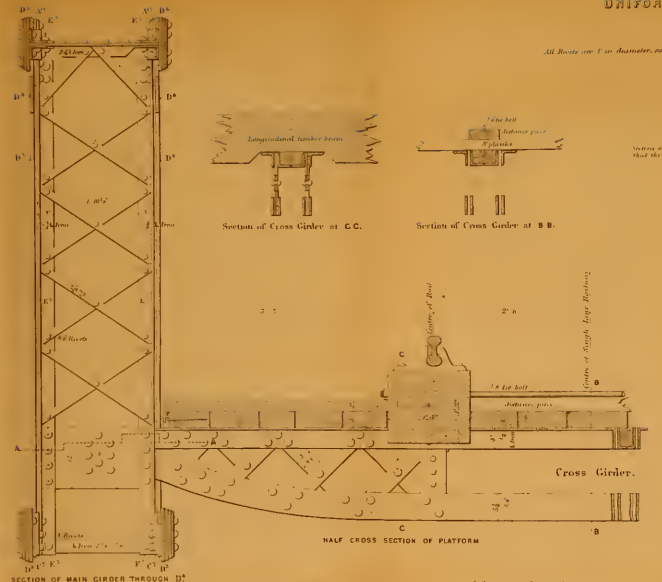
HALF HORIZONTAL SECTION THROUGH CENTRE OF LOWER BOOM

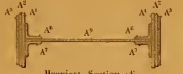
UNIFORM STRESS IN GIRDER WORK.

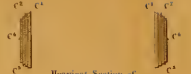
BRIDGE Nº2. DETAILS.

All Rivets are ⅞ in diameter, excepting those which fasten stiffening Bars to Struts, which are ¾ in diameter

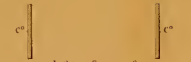




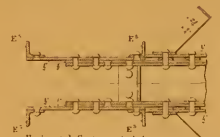


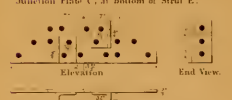


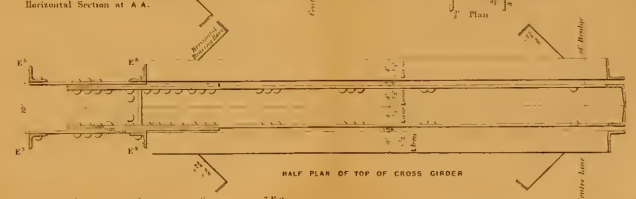
Sections of End Strut Box similar except that the side plates are ⅜ in thick

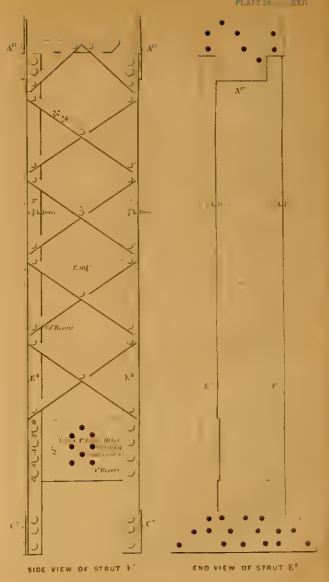


The Junction Plates of the other Struts are similar to these in effect









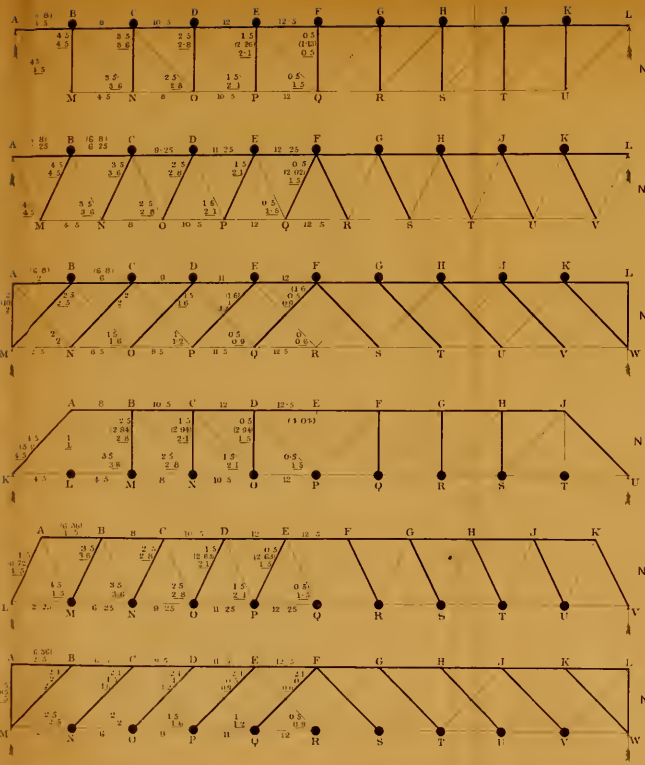
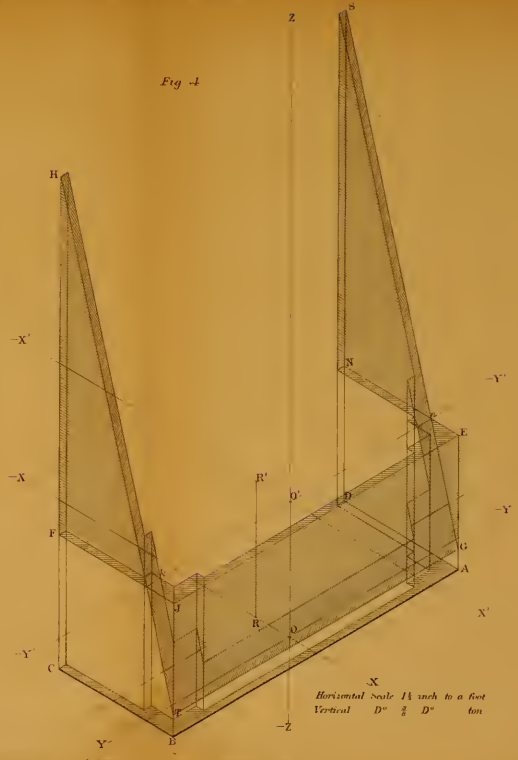
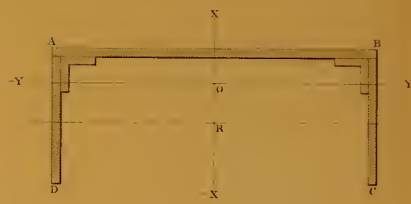


Fig 4



Fig



Minutes of Proceedings of the Institution of Civil Engineers, Vol. LXXIV. Session 1882-83.

surrounding them, to resist the transverse strain to which those sides would there be liable. As regarded, however, the question of uniform stress upon the web bars themselves, it would, of course, be necessary, in order to fulfil that condition, to make the centre of gravity of the group of rivets or bolts attaching each bar to the trough, to lie in the axis of gravity of that bar.

In Fig. 9, the lines C D, C B, and A C A, were respectively the axes of gravity of the two bars of the web and of the trough, all three of them meeting at the point C. By "axis of gravity" of a bar, was meant the longitudinal line or axis which intersected the centre of gravity of every cross section. If the desideratum of uniform stress could be achieved in that way, the explanation would be, that the forces acting through the diagonal bars, might be considered as concentrated in the lines of action of their resultants, D C and B C, respectively, and if that were so, the resolution of those forces in the horizontal direction, could not take place until those lines of action met, and if the point of meeting was at C, in the axis of gravity A A of the boom, then the horizontal resultant would act along that line. The transverse strain before alluded to as acting upon the sides of the trough immediately contiguous to the joint, and the distortion produced by it, were important objections to that mode of combination. But if circumstances compelled the use of the trough, he thought no other attachment could be selected with anything like scientific propriety.

Mr. G. H. Phipps said, as certain views which he entertained, with respect to the strains upon girders, had been referred to by the Author, he wished to say a few words upon the subject. He would first, however, draw attention to the designs of the girders adduced by the Author, as in his opinion securing a high degree of economy. One of these, designed for carrying a railway by means of cross bearers at the bottom of the girder, was on the plan of what had been described in a recent Paper on American Iron Bridges,[1] as the "Murphy Whipple Truss," and it might be remembered that Mr. Bramwell in the course of the discussion upon that Paper, contended that it was considerably less economical than the ordinary girders used in this country.[2] The Author of the present Paper did not however contend that that class of girder, considered purely in the theoretic manner adopted by Mr. Bramwell in his comparison, would come out more economical than the Warren, Trellis, or other girders filled in with open triangles, but he traced the economy of his girders to the fact of the larger proportion of the iron work being in a state of tension, that the compressed members were shorter than in the others,

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxii., p. 540.
[2] *Ibid.*, p. 560.

and also that his trusses contained less waste iron. Arguing from the well-known fact, that a greater force per square inch could be safely applied to iron in tension over iron in compression, and assuming that, according to the laws of columns, the compressed members required an additional quantity of iron in the shape of bracing to steady them, which the Author took to be in the proportion of the cubes of their lengths, he thus considered that he obtained a cheaper girder than by the other systems.

It appeared to Mr. Phipps, that the subject required much more consideration, before it could be laid down that the weight of the bracing in compressed members must increase as the cubes of their lengths. When the width between a pair of compressed uprights remained constant, the stiffness of the assemblage would not be largely modified by the proportions of the diagonal bracing, but would depend much more upon the sectional area of the uprights themselves. The case was very similar to the relative deflection of a pair of girders of the same depth, but differing in length, where the amount of deflection would depend much more upon the magnitude of the booms than on that of the diagonal bracing.

He would now pass to the remarks on the importance of confining the line of force exerted upon any member of a truss, to its true axial line, by which term he would designate the line of the neutral axis. This was a point to which he had devoted much consideration, and, as was known, he had embodied some of his views upon it in the discussion upon the Charing Cross Bridge.[1] He felt gratified that the Author of the Paper had taken up the subject in consequence of what fell from him upon that occasion, and that he considered the views then expressed to be in accordance generally with the deductions of Professor Rankine; but he thought that too high a value had been attributed in the Paper to the detrimental effects due to the absence of coincidence in the line of the forces applied, and the axial lines of the booms of a girder. The Author appeared to have taken, as the measure of the detrimental action on the booms, the total compressive force applied, taken into the distance of the line of application of that force from the axial line of the boom. Now, Mr. Phipps believed, that this would only be found correct on the supposition of the boom consisting of a number of detached props, abutting end to end, against each other, and strained out of the centre as above. He considered that continuity in the boom, from end to end of the girder, modified the detrimental effects of the absence of centrality in the application of the strains very largely.

To explain this he would refer to four diagrams (Figs. 10 and 13.) The first (Fig. 10) showed a boom compressed out of the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxii., p. 535.

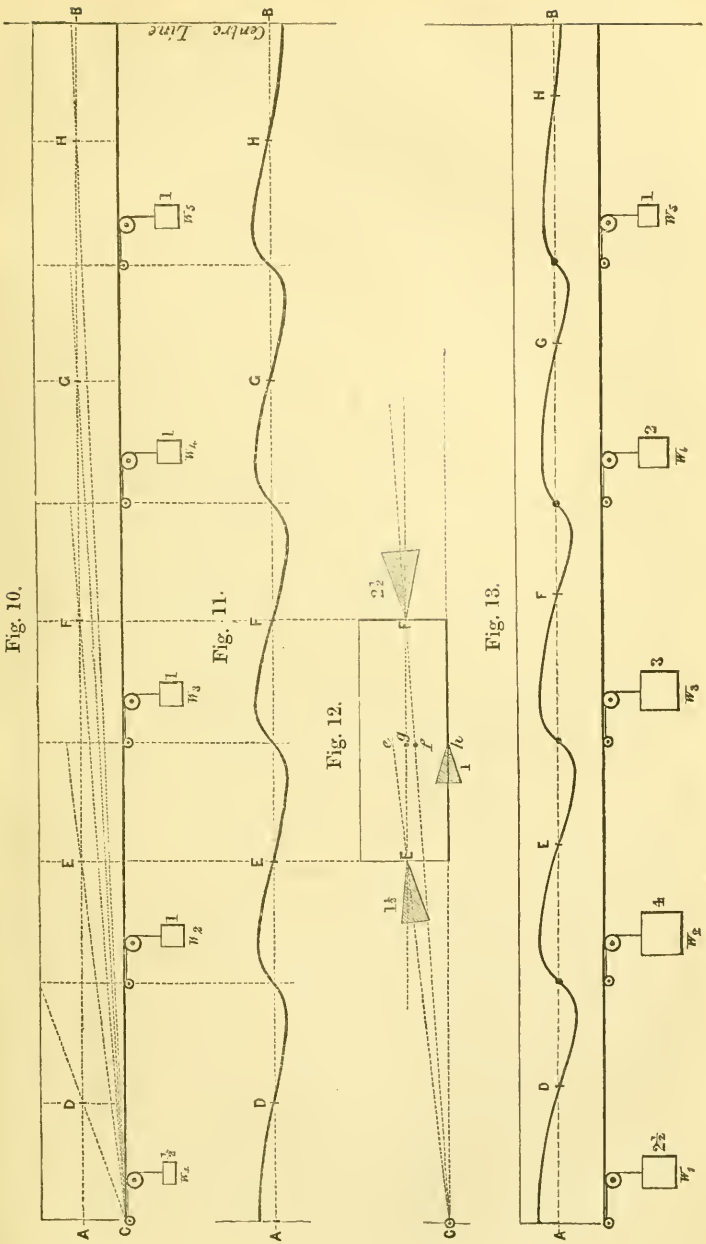


Fig. 10.
Fig. 11.
Fig. 12.
Fig. 13.
Centre Line
A
B
C
D
E
F
G
H
1
W_5
1
W_4
1
W_3
1
W_2
$\frac{1}{2}$
W_1
$2\frac{1}{2}$
$1\frac{1}{2}$
1
e
g
f
h
1
2
W_1
3
W_3
4
W_2
$2\frac{1}{2}$
W_1

centre at regular intervals by a series of equal forces, which was the condition of a girder carrying a central load. Another diagram (Fig. 13) showed a boom compressed by forces similarly applied, but increasing from the centre towards the extremities in arithmetical progression, being the state of things which obtained when a girder was equally loaded all over. Both booms were supposed to be of uniform section throughout.

Figs. 10, 11, and 12 referred to a beam bearing a central load. The points D, E, F, G, and H were equidistant from the points of application of the straining forces. The dotted lines C D, C E, C F, &c., showed the direction of the resultant pressures through the different compartments of the boom; thus, referring to one compartment E F, Fig. 12, there was a force acting in the direction of C E, continued from E to *e*, of which the horizontal component was $1\frac{1}{2}$. Again there was a force acting in the direction of F C, passing within the boom from F to *f*, of which the horizontal component was $2\frac{1}{2}$. There was a third force applied at *f* horizontally equal to 1, and these three forces kept the portion E F of the boom in repose. Thus the distance of the force of $2\frac{1}{2}$ at F was never farther from the axis than *g f*, a much less distance than *g h*, the distance from the axis to the line of application of the forces. In Fig. 11, the letters D, E, F, G, and H showed the points of contrary curvature equidistant between the points of application of the compressive forces, all the curves being of equal versed sines. Fig. 13 showed the application of the above views to the case of a boom of a girder where the load was uniformly distributed. In this case the points D, E, F, G, and H were not equidistant from the points of application of the forces, but were considered to divide each bay inversely in the proportion of the two forces. The curves of the axis in the different bays would in this case be no longer similar, but continually diminish in altitude from the extremity at A to the centre at B.

He considered that, in each of these cases, the boom was thrown into a serpentine figure, in which the inflections were, in the first case referred to, all of precisely equal versed sines; but that in the second, the versed sines of the curves between the points where the compressive forces were applied, continually diminished in altitude from the extremities inwards, until, at the centre, the curve merged into the axial line of the boom. Upon these principles, there would be found a point in every bay, intermediate between the points of application of the forces, where the inflections of the curve of the boom crossed the line of its axis, and became there points of contrary curvature. A consequence of this would be, that as at those points no flexure existed, the compressive force must necessarily pass through them. The boom might be separated at those points, whilst still fulfilling its proper office; each

portion would then be kept in repose by three forces, namely, one at each end, acting angularly inwards, the third force being that applied by the compressing force proper to the bay under consideration. In this manner the resultant pressure would pass much nearer to the axial line of that portion of the boom than the distance of the line of the applied forces from the same axial line. In the case of the Charing Cross Bridge, he had made these allowances, but the effects would have been far worse, if calculated according to the method described in this Paper.

Before concluding, he would just advert to an instance which had occurred to him of the bad effects of straining matter transversely, which was at the same time subject to considerable strain in the direction of its length. He alluded to the Hungerford Suspension Bridge, lately removed to make way for the Charing Cross Bridge. That bridge was, generally speaking, an admirable work; but the defect alluded to consisted in the manner in which the weight of the platform, passing load, &c., was conveyed to the chains. The links were 24 feet in length by 7 inches deep, and one half of the load on each chain was supported by the centre of the links, giving transverse strain to the iron. He had computed that if the calculated maximum strain per square inch was 6 tons, it would be increased to 10 tons from the above cause.

Mr. J. M. Heppel agreed in thinking this Paper one of a class exceedingly valuable. It dealt with the principles of construction, and it pointed out several examples in which those principles had been carried out with a great measure of success. He thought the warning held out should not be disregarded; that whereas Engineers had been building bridges which were supposed, according to previous calculations, to be subject only to a strain of 5 tons or 6 tons to the square inch, they had been built in such a manner that the bridges had been subjected to a strain of more than twice that amount. He thought that was a fact which ought to attract serious consideration, and which opened questions requiring clear and satisfactory answers.

He agreed that, in structures of that kind, it was most desirable that the strain should pass accurately through the axes of the members of the truss which were resisting that strain; and the Author had done good service in pointing out the examples of two bridges constructed in such a way that that principle was entirely carried out, and which showed that no inconvenience, or difficulty in design or execution, was occasioned by so doing.

Where Mr. Heppel differed from the Author was, in thinking that in the cases where that principle had not been so strictly adhered to, the consequences had not been quite so disastrous as had been suggested. But, after the discussion which took place two years ago on the subject of the Charing Cross Bridge, and the

observations made on that occasion by Mr. Phipps, in which he generally concurred, and which had just been more fully explained, it was not necessary to enlarge upon points which were at that time brought very completely under consideration. He felt confident, that, whoever had the advantage of reading the Paper, would find that it contained a precise elucidation of the action of a force eccentric to the axis of the resisting body, and in fact, though it was a little more elaborate, the demonstration was substantially what had been pointed out in the discussion he had alluded to. But, he thought, in the case of the top and bottom members of a truss, the forces were brought on in a manner which differed materially from that which served as the basis of the demonstration; because, though where each individual force was brought on, an action obtained which was very well represented by the Author's diagram, the way in which the forces were really brought on to the top and bottom members of girders was by no means the same. If a single force was applied, not coincident with the centre of resistance, precisely that action took place which the Author had shown; but with a large truss, like the truss of a bridge, in the first place, the force was not necessarily coincident with the point of junction of the first diagonal; but, by means of the strong vertical member which connected that diagonal with the body of the truss, it was in fact brought on where the greatest resistance occurred—and that was, where there was the greatest mass of metal; so that the force induced by the first system of diagonals was close to the top, or certainly not far from it. Thus, at the next point of connection of the diagonals, there was, no doubt, a new force applied, the action of which was nearly such as that supposed in the argument; but that was compounded with the force already accounted for transmitted along the top, so that the resultant was considerably thrown up; and that redressive action evidently accumulated towards the middle; so that whatever evil existed was at its maximum near the end, and it was not to be denied that many structures were more or less subject to it, so far as it went. He thought, however, for the reasons given, that the extent of that evil was restricted within much narrower limits than might be apprehended from the comparison in the Paper. It was stated that, upon deviating a very little out of the centre of resistance, there might be as much as 12 tons of strain on the part which was least calculated to resist it, and not more than half a ton on the part which was most calculated to resist it. That, for the reasons alleged, he could not quite concur in; and as he had built, both under direction and on his own responsibility, many bridges where, he was obliged to confess, the principles laid down in the Paper had not been so completely observed as probably was desirable, he hoped it might be apparent, from the course of the

discussion, that it was not a reasonable inference that such structures were at all unequal to the work required of them. At the same time it was undoubtedly a sound principle, that all the forces should be made to pass accurately through the axes of resistance. The profession was, in his opinion, much indebted to the Author for placing that principle in so clear a point of view, and for having shown, by executed work, that there was no practical difficulty in carrying that principle into effect.

Mr. Edward Woods said, as regarded the principle of construction recommended in the Paper, it was one which must commend itself to the judgment of every Engineer. It was no new principle in the construction of machinery, because the aim of all was so to distribute the parts, that the pressure should be transmitted in the direction in which it was required to go, and in such a position with regard to the form of the part through which it had to pass, as might be found to produce equal pressure and strain on every part. As in the connecting rod of a steam-engine, the centres of bearing were never placed out of the axis of that connecting rod, so, unless something prevented it, the joints of a bridge ought to be placed in such a manner as to secure equal strain throughout every part of the bridge. The remarks in the Paper were, however, more applicable to triangular trusses, or to lattice bridges than to plate girders. In the plate girder, the strains might be conceived as passing through every part of the web, and transmitted to the upper and lower members, and uniformly transmitted; but in triangular girders, it was of essential importance to distribute the pressures in the way indicated in the Paper.

He agreed substantially that the difference of stress or strain, as between the upper and lower edges of the trough, could not be so great as that which was suggested in the Paper; and probably the Author would admit that there might be causes at work which tended much to modify the proportion. But at the same time there must, undoubtedly, be unequal distribution in such a case as was illustrated by Fig. 3, Plate 27, where the centre of gravity of the joints was on the line R, and so much below the line O of the axis of the centre of gravity of the section. There must, in such a case, be a tendency to transverse strain in the girder, and parts of the girder consequently must be subjected to strains in excess of those which such parts were assumed to bear, and had been calculated for.

Mr. F. W. Sheilds remarked, that the strains on the top of the girder were caused by the action of the diagonal bars, and were, therefore, to a certain extent, of a complex character, as there was not only a horizontal pressure along the top flange, but also a downward pull, inasmuch as all vertical weight was taken, in the first instance, by the diagonals, which communi-

cated the strains to the flanges. He thought that effect should not be forgotten in designing the form of the top flange; and therefore, if that flange were considered as a member bearing horizontal strain alone, without taking the vertical strains also into consideration, the design for it would be defective. The resistance to vertical strain would, no doubt, be borne by the whole depth of the girder; but there was still a considerable downward pull, as well as a horizontal pressure on the top flange. He did not think, therefore, that Engineers in their previous practice had been following a wrong principle to the extent supposed by the Author, who had in fact taken as his principle, that the top flange was simply in the position of an ordinary loaded column. Doubtless, in very large bridges, and especially in those of 600 feet span, the distribution of the strain through the centre of the axis should receive all due consideration; but in smaller bridges, the prejudicial effect of what had been done hitherto was rather overrated. If, for instance, a built T-iron section for the top flange were loaded vertically, it would be found that, with the table up and the web turned down, the T-iron flange would bear more vertical weight than in any other position; and he thought a better result could thus be obtained than from the form adopted by the Author. In the first place, it was advisable to put the greatest amount of section in the top of the flange, where the strain was always greatest and where fracture began. In the next place, there was the practical advantage of leaving a clear space in the lower part of the flange for the attachments of the diagonal braces: and in the third place, there was an opportunity of getting (in cross section) a single set of diagonal braces, which was quite sufficient for bridges of ordinary size, instead of a double set as shown in the Author's design. Moreover, experience seemed to show, that if frequent and rigid connections were made between the top and bottom flanges, a better result ensued than by making very few connections, and that thus it was better to make the braces of close lattice work than on the single triangulation system.

In the construction then under consideration there was also, he thought, something seriously defective, namely, that the diagonal ties did not extend in both directions from their points of intersection on the flanges, and so make proper provision for the conveyance to both points of support on the piers, of any loading which might rest intermediately between either pier and the centre of the girder. Therefore, scientifically speaking, that design would have a certain amount of weakness and deflection, which it would not have with more frequent and properly disposed connections between the top and bottom flanges. He thought the Author had proposed principles of construction worthy of attention, though the details shown in his designs for these small bridges were probably not as

advisable for adoption, as those used in the common and ordinary construction, viz., frequent lattice bracing, or plate-girder bridges.

Mr. ROBERT MALLET remarked, that the present Paper appeared to come within the latter of the two classes of Papers—the purely practical and the practico-theoretical—chiefly brought before the Institution. Its reasonings were thus of a character that could not be fully followed at the instant of hearing, but he thought it one which would, when it should appear in print, do credit to the Institution. It was characterised throughout by care, lucidity, and logical sequence.

As to the general principle insisted upon, he presumed there could not be the shadow of a doubt in the mind of any one present as to its correctness; though much diversity of view might arise, as to whether it might require to be rigorously acted upon in practice in all cases, or to what extent it must necessarily be employed in any particular case.

If it were asked whether it was a matter of indifference in the application of an insistent load upon the end of a large prism, suppose of granite, whether the centre of pressure passed through the axis or in the plane of one of the sides of the prism, there would be no hesitation about an answer; but it was, in fact, the same question which now engaged the attention of the Meeting, only in the place of granite, iron had to be dealt with, which was a still more compressible thing, and the question as regarded it, therefore, was in certain respects even more important. But yet, he thought, that how far the principle which the Author had so ably elucidated required to be rigorously applied in practice, must depend upon the special circumstances of each particular case. If the strain at the extreme edge, or at any point, of a prismatic member of a structure was there of an intensity amounting to a crippling strain of the iron, then the principle had been dangerously disregarded, and every approach to that was *pro tanto* a waste of material, or of strength, or of both.

But in large structures it was necessary to consider all the distortions of each member of the structure viewed as a whole, and in these structures the final distortions, so viewed, might be such as to much alter the lines of direction of forces originally designed in perfect accordance with the principle of the Paper, and so that the difference of strain between one edge of a bar and the other might become very important, or *vice versâ*, strains passing unsymmetrically in the drawing, which viewed the whole as a rigid structure, might approach greater symmetry after the load had been applied. In large girders, like those of the Charing Cross and Londonderry bridges, every other member of the structure required to be distorted before any effect was produced upon the booms, and it was only after that had occurred

that it was possible to determine the distortion of the booms themselves, and to what extent the line of pressure at any section, and normal to it, was out of the centre of gravity of that section.

For himself, as regarded the application made by the Author of his principles, to the fixing the proper form for the cross sections of the top and bottom beams of large girders, he should be disposed to mitigate the evil of the simple trough or ⊔ form, by putting angle irons inside the open edges, so as the better to equalize the section. But in some large structures he had designed, he had adopted the simple trough form, not because of its goodness, but rather in face of its disadvantages, and solely because that form presented great constructive conveniences; and he might be permitted to say, that he felt some satisfaction, as the Author of one of the prize designs for the Londonderry bridge, to find that that design had been adopted in all its main features for that bridge as since executed. It was with still greater satisfaction that he lately saw at Bordeaux, that the same general design had been adopted in one of the noblest girder-bridge structures probably in Europe, namely, the viaduct bridge over the Garonne, just above Bordeaux, which connected the Central of France railway with the eastern system of French railways. The diagonals and verticals of these girders were not connected by large pins with the trough-shaped booms, but by rivets. He considered these connections better than pins, though also against strict theory, inasmuch as with rivets the amount of strain was not concentrated so much at one point of the iron. Pins were no doubt theoretically the right thing, but riveted connections, he thought, were practically the best. He would direct the attention of the members to the Bordeaux bridge, of which he believed little was known in England, as being well worthy of careful examination.

Mr. F. J. Bramwell said, this was a matter on which he wished to say a few words, not merely because his name had been alluded to in the Paper, but because the subject was one that deserved the attention of all. The Author of the Paper had the primary object of showing by it the importance of uniform stress in girder-work, and the secondary object of showing how, if he proved the necessity of this uniformity, it might be carried out; and incidentally he alluded to two girders constructed in a manner which he believed had fulfilled the condition of uniformity of strain, and took occasion to give his reasons for selecting the particular form of truss employed in preference to other forms of truss; and then slightly referred to that which he (Mr. Bramwell) was supposed to have said in the discussion on American trusses. Mr. Phipps had also alluded to that which he (Mr. Bramwell) was imagined to have said on that occasion. If he might be allowed to say so, both those gentlemen were in error in their recollection of his remarks, for

that which he had said certainly was not in depreciation of the Murphy-Whipple truss. It might be remembered that three descriptions of trusses were then brought under their consideration, viz., the Bollman, the Fink, and the Murphy-Whipple. The former two were condemned by him for the reason that they laboured under the radical error of conveying the mere local strains to the ends of the principal compression member, and further that this extra load on the compression member was obtained at the expense of a large extra amount of iron in the tie rods. From these two causes these trusses required a larger amount of iron than that employed in either the Warren or the double-diagonal truss. But with regard to the Murphy-Whipple truss, it would be found he had stated it approached so nearly to those in use in England, that there was little to say upon it, except that in a girder where any of the struts or ties connecting the top and bottom members were vertical, there must be some want of economy in the material, inasmuch as those struts or ties which were vertical would only carry the girder, and would not assist in the progression of the stresses from end to end of the girder. He believed this was all he had said in depreciation of the Murphy-Whipple truss.

This had been his view with respect to such a truss; but the Author of the Paper had ingeniously endeavoured to show that although, considered abstractedly, there might be a small percentage of loss in it, as compared with Nos. 1_A and 1_B, nevertheless, when considered as used in common practice, an allowance must be made which would not only do away with the loss, but would produce a positive gain, and this allowance was due to two sources: the one that certain members which were, by calculation sufficient if made of a particular thin section, in practice could not be so made, because such thin metal could not be used, and therefore iron stronger than the theoretical section had to be employed. This allowance of excess the Author had shown by the bracketted figures in Plate 27. The second and principal source, however, to which was due, according to the Author, a departure from the theoretical amount of metal in a girder where the struts and ties between the top and bottom were all sloping, and which departure involved an allowance of extra metal, was this: that the stiffening material required for the struts had to be increased as the cubes of the length of the struts; and having assumed a particular amount of material in the girder as necessary for such stiffening, the Author took that as the datum, and then showed that when this quantity was cubed, according to the increased length of sloping struts in the Warren and double diagonal trusses, there would be a large increase of stiffening, and that this increase would make these girders less economical than those with vertical struts, which the Author had adopted.

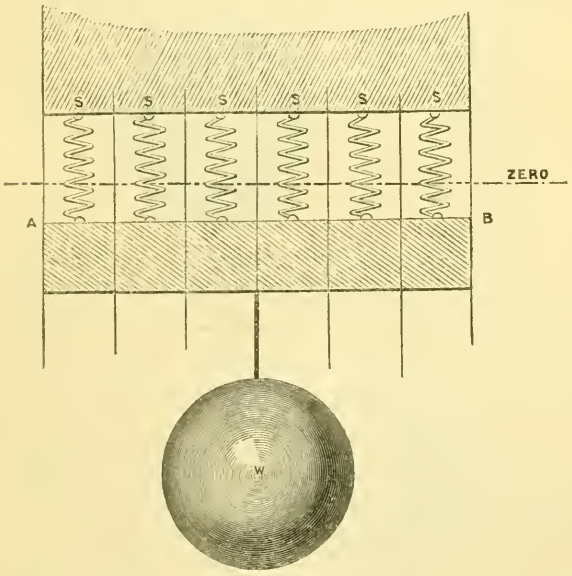
Mr. Bramwell thought there were two errors in that reasoning. First, it went on the assumption that the struts, as ordinarily made, viz., with material of uniform section from end to end of the strut, were those which bore a pressure with the least consumption of iron. He did not agree in this being the best construction for a strut; as he believed that a trussed post, such as was to be found in the Murphy-Whipple trusses, was a more economical use of material, and that when such a construction was employed, a small increase of material would be sufficient to prevent the flexure under pressure. Such a strut as this was used by Mr. Cowper in the great roof at the Birmingham Railway Station. Next, even assuming it could be demonstrated that the struts shown in No. 1_B truss were of the most economical section, nevertheless each one of those struts was crossed at the middle by a tie; and if the ordinary practice were followed of joining those ties to the struts at the point of crossing, the struts so joined would be reduced to half their length, considered as unsupported pillars, and thus so far from their being longer pillars than in a truss where they were vertical, they would be by far the shortest, and would therefore require the least amount of stiffening material. On these two grounds he thought the Author's ingenious theory failed, and that he had not proved that either a Warren or a double-diagonal truss girder was the one which consumed in practice the largest amount of material. Mr. Bramwell wished to remark, that although the girder had been spoken of as the Murphy-Whipple truss, it was, in fact, a truss well known in this country. Those who remembered the roof of the nave of the Exhibition building of 1851 would recollect that this form of girder was used to support it. He thought the better term for this form of girder was the N truss. The girders of the roof of the nave of the Exhibition building, of which he had spoken, though to the eye they were double diagonals, were, in truth, girders of that description, for the diagonals at cross angles were nothing but pieces of wood put in to give a better appearance than could be obtained from the N form.

Mr. Sheilds had objected to this form of truss upon grounds which Mr. Bramwell could not follow. He had said, in effect, there was the objection that if the weight at the top of one of these pillar struts, required to be transmitted to both ends of the girder, there was no means of transmitting it down such members as were merely ties; but Mr. Sheilds must have overlooked that the Author had provided for this in the ordinary way, that was, that in those ties which occasionally had to act as struts, he had added the stiffening which enabled them so to perform that function.

Having said this much upon the question of the particular form

of truss adopted, he would ask permission to take up a little more time in addressing himself to the principal subject of the Paper,—that was as to the effect upon material, either in compression or in extension, due to putting the load or strain out of the centre of gravity of that material. Mr. Bramwell had felt some difficulty in following the Paper as it was read, and he now wished to put the question in a shape which might be taken in by the eye, and which certainly brought the matter more home to his mind than it could be brought by the consideration of the Author's very abstruse calculations. The diagrams he exhibited were made in accordance with some figures he had used three or four years since, when endeavouring to ascertain the effect of loads in producing flexure in columns. He had, however, changed them to diagrams exhibiting the effect of tensile strain, as being somewhat more convenient. Instead of looking upon the section under consideration as composed of an infinite number of elastic particles, he had for the purposes of investigation assumed that this particular section

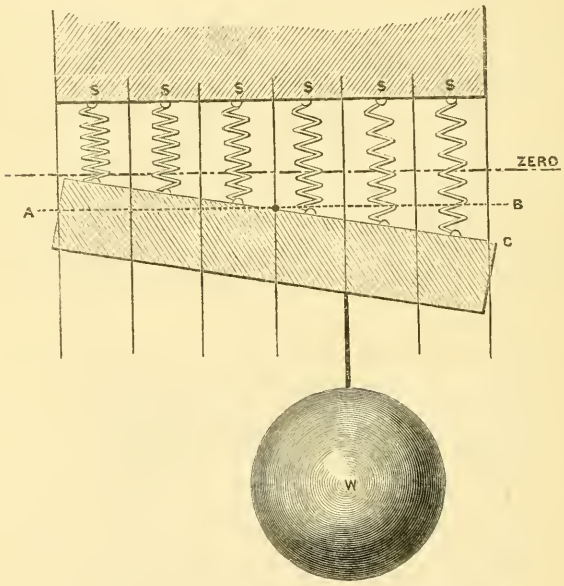
Fig. 14.



was composed of a definite number of springs. In Fig. 14, he had assumed six equal springs, and he had assumed that if there were no weight upon them they would be at the zero line. He next assumed the load W to have a weight of 6, and that when

put in the centre it would extend the springs a distance of 1 each, and would bring them down to the horizontal line A B. If that were the condition when the weight was in the middle, it was easy to show, if the weight were moved one-sixth out of the centre, (as in Fig. 15), that the result would be to leave the middle of the beam,

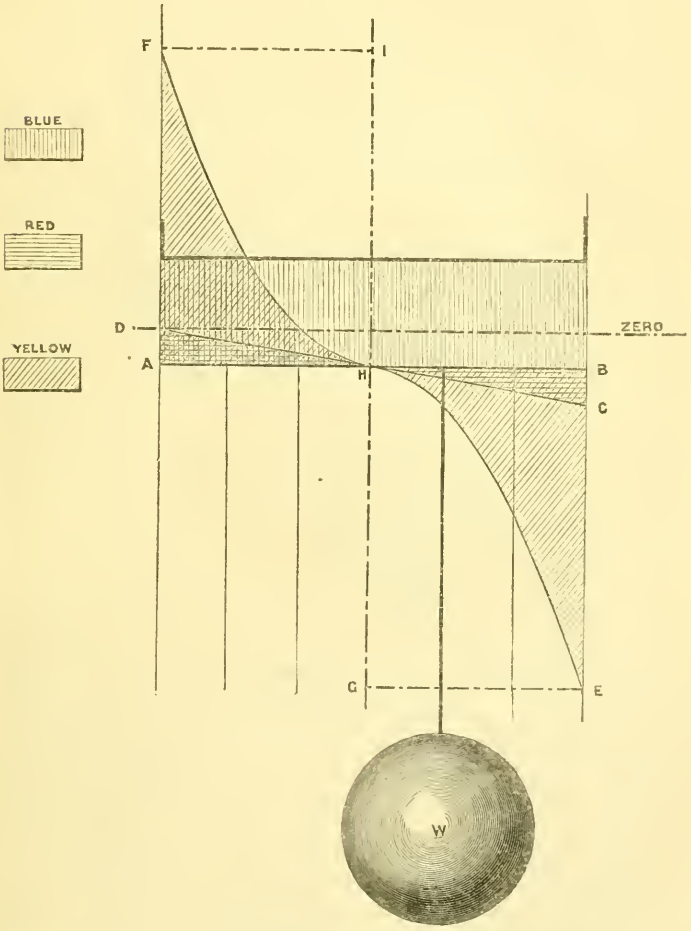
Fig. 15.



to which he had represented the weight as fastened, at the same height of A B as before, and to turn the beam round the middle point of A B as a centre ; one end would then come down through B C, while the other went up through A D ; so that, as Mr. Phipps said, there would be double tension upon the side nearest to the weight. That was true with the weight one-sixth out of the centre of a bar of uniform section. It was not strictly true with the six springs, as to be quite accurate it was necessary to assume an infinite number of springs : in which case the effect would be as seen in Fig. 16. Assuming the space between the black horizontal line and the zero line to represent an infinite number of springs, then if the weight be supposed to be placed in the centre, the extension of all the springs would clearly be equal, and might be taken to be the distance between the zero line and A B. Then if, as before, the weight be put out of the centre one-sixth of the width of the bar, the tendency would be to turn the line A B round about the point H, but directly A B turned about that

point, the tension of the springs to the right (in the diagram) would be increased, and the tension of those to the left hand diminished; now the extra tension of the right-hand springs would tend to restore equilibrium, and the effect of any spring, say, for instance, the one at B, would be measured by its extension B C,

Fig. 16.



multiplied into B H, (the distance of B from the centre H); and the effect of any other spring between B and H would be measured by its extension multiplied into its distance from the centre H.

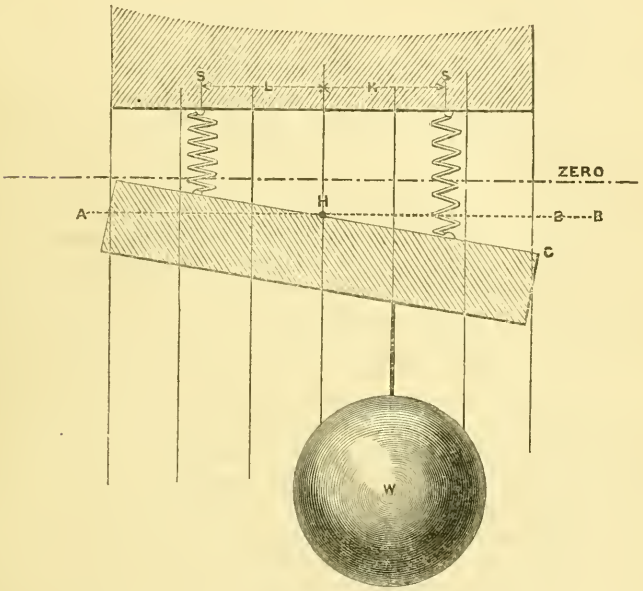
The extra extension of the springs between B and H would

gradually diminish from B to H until at the point H, the extension was zero, and if B C represented the sum of the extension at B, the extensions between B and H would be represented by the triangle B H C. Further, if B E be taken to represent the effect to restore equilibrium due to the extra tension of B (viz. B C × B H), then the sum of the effects of all the other springs between B and H would be represented by a curve coloured yellow in the diagram, and this curve, it would be seen, was a parabola, because the extension and the value of the extension being each of them as the distance from the centre H, the effect (*i. e.*, the extension multiplied into the value or distance from the centre) would be as the square of that distance. Now the area of the parabola B E H was $\frac{1}{3}$rd of that of the surrounding rectangle B E G H, and the effect, therefore, to restore equilibrium would be $\frac{1}{3}$rd of B E G H or $\frac{1}{3}$rd of the rectangle compounded of B H, and the extension B C multiplied by B H; represented by B E. It might similarly be shown, that the effect of the diminished tension of the springs to the left of H, would be $\frac{1}{3}$rd of the rectangle A F I H, which was equal to H G E B, therefore the total effect to restore equilibrium would be $\frac{2}{3}$rds of the rectangle (B C × B H) multiplied into B H, which was equal to $\frac{1}{6}$th of the rectangle (B C × B A) × B A, because B A was double of B H. Now the whole disturbing force was equal to the effect of the extension of all the springs when equally extended multiplied into the distance of the weight from the centre: and the effect of the extension of all the springs = the extension or distance from zero to H multiplied into the number of springs represented by the length A B, and as the distance from the centre = $\frac{1}{6}$th A B, the disturbing force = $\frac{1}{6}$th of rectangle (zero to H × A B) × A B. Hence it would be seen that, in this case, equilibrium would be restored, when the distance B C was equal to the original extension from zero to H, so that when the weight was moved $\frac{1}{6}$th of the width of the bar from the centre, the extra tension on the edge nearest the weight would be equal to the original tension with the weight in the centre, and the strain therefore on that edge would be double that which it would be with the weight in the centre. If the weight be placed at double this distance of $\frac{1}{6}$th from the centre, then double the amount as ascertained in the foregoing must be added to the original tension at B; if at treble the distance, then three times the amount must be added, and so on in an arithmetical progression. Thus, if the strain with the weight in the centre be 1, then the strain at B with the weight moved $\frac{1}{6}$th, would be $1 + 1 = 2$, with the weight moved $\frac{2}{6}$th it would be $1 + 2 = 3$, with the weight moved $\frac{3}{6}$ths, $1 + 3 = 4$, and so on.

Mr. Bramwell would suggest that an experimental apparatus to illustrate the action of an infinite number of springs, or in other words, an elastic bar might be made by using two springs, the

united strength of which should be equal to the elastic force of the bar. Such an apparatus was represented in Fig. 17. The springs were placed at such a distance L K from the centre as was equal to $\sqrt{\frac{1}{3}}$ of the half width of the bar. The reason for this position was, that the effect of a spring in counteracting a

Fig. 17.



disturbing force varied, as had been already shown, in proportion to the square of its distance from the centre, and the average of such effects would be at $\sqrt{\frac{1}{3}}$ of the distance from the centre to the extreme edge. With such an apparatus the weight, on being shifted to various positions along the lower bar, shown in Fig. 17, would produce effects corresponding with those calculated when considering Fig. 16.

The foregoing was doubtless a crude mode of looking at the question, but it was a mode that could be appreciated better than a large number of figures; therefore Mr. Bramwell had ventured to submit these diagrams for consideration. But though he believed the conclusions of the Author were perfectly true, and he might say, he had applied the system of calculations just mentioned to the trough section spoken of by the Author, and the results agreed with those the Author had given; and though he thought that the Author's

view would be a correct exposition of the case, if the section of the trough were looked upon as being of a number of parallel springs independent of each other, he could not bring himself to believe that the effect spoken of by the Author was produced in the girder of a bridge. He was inclined to this view for the following reasons: The Author of the Paper had assumed a section taken quite close up to a pin nearest the centre of the bridge; the section was taken thus in order to get rid of the objection of curvature of the compressed member; but if the section be so taken close to the pin, then unless this particular pin put the whole pressure on the truss, the reasoning pursued by the Author would not be applicable to the case. Now the fact was that the pressure, in place of being entirely produced by this one pin, was the accumulation of successive increments put on gradually from the end to the centre of the girder, but the particular pin adjoining the section taken, put on the least of all these increments: therefore the pressure, instead of being applied immediately behind the section taken and at the assumed point, came in reality from points far removed from this section, and therefore before arriving at the point under consideration the various pressures were able to distribute themselves over the section. In illustration of this he would take the case of a column put into a tube, so that it could slide freely through the tube, but could not bend, and then imagine a weight put on the column out of the centre, when, according to the Author's views, whatever the length of the column might be, every transverse section taken throughout that length would have its parts as much irregularly strained as the parts were said to be in the section of girder laid before them; but Mr. Bramwell did not agree with this notion, because he thought that though the weight was put out of the centre, yet when the column was kept from being deflected, it might be treated as being acted upon in the neighbourhood of the load diagonally, but as having this diagonal strain corrected, by the resistance of the surrounding tube preventing deflection, so that in a short distance from the point of application, the load would become resolved into a strain parallel with the centre of the column, and diffused uniformly over its section. He believed that a similar result would be produced in a long girder in which the top and bottom members, by being supported at frequent intervals, were practically prevented from bending; and if this were so, the effect apprehended by the Author could not be produced.

Mr. Bramwell wished, therefore, to express his dissent from the Author's views, as to the extent of the evil that would be produced in a girder by the pins that put the strain on the top and bottom members not being situated in the centre of gravity of the section of those members; but while he dissented so far,

he at the same time agreed with the Author's statements entirely when the effect spoken of was considered as produced in the parts of an elastic material immediately adjoining the point at which pressure was applied. Having read through the Paper, Mr. Bramwell could bear testimony to the labour that had been expended upon it, and he felt that a debt of gratitude was due to the Author for the infinite pains he had taken in preparing the Paper, which combined in a happy manner great theoretical investigation with good practical results.

Mr. W. H. BARLOW would say a few words upon the subject under discussion, because some years ago he conducted a series of experiments upon the performances of plates, or a series of plates, when strained in lines which did not pass through the centre of gravity of the plates. Those experiments were made in connection with Papers which he read before the Royal Society.[1] The plates were 2 feet long, 6 inches wide, and $\frac{1}{3}$rd of an inch thick. Each plate had cast upon it two small ribs, at distances of 12 inches apart, and in those ribs, six holes were made in which to insert delicate measuring instruments. He would state broadly the results arrived at.

First: It was found that the mean elongation of the plates was the same with the same weight, at whatever part of the plate the strain was applied.

Secondly: When the strain was applied along the line of the edge, it produced an extension along that side, accompanied by a compression on the opposite side.

When the weight was one-sixth out of the centre, it produced a condition in which there was extension on the one side, with no action on the other side. When the force was applied in the line of the edge of the plate, the extension on one side was double the compression of the other, but the mean extension of the plate was the same as if the weight hung in the middle.

The next thing ascertained from that experiment, was an angular movement, and it was found that the angular movement varied as the weight into the distance of the line of application of the force from the centre of gravity.

Therefore so far as the theoretical expression just given by Mr. Bramwell went, it was borne out by those experiments completely; and he concurred with him in the observation, that if that plate was free to move under those strains, it did exhibit weakness; yet if it was confined like a bar within a cylinder, then those effects ceased to act, or were much mitigated. But although he concurred with the theory as applied to detached pieces, he did not agree with it as regarded the continuous boom of the girder,

[1] *Vide* Phil. Trans., 1855, p. 225, and 1857, p. 463.

because the continuity of the boom prevented any considerable amount of flexure between the points at which the diagonals joined. With regard to the different forms of girders, his opinions on that subject had been so completely expressed by Mr. Bramwell, that he would not trouble the Meeting by repeating them.

Mr. Bramwell was glad to find, that Mr. Barlow's experiments had corroborated the results that could be attained by continuing the consideration of diagram Fig. 16. He had already stated, that if the weight were moved $\frac{3}{6}$ths out of the centre, *i. e.* to the edge of the bar, the effect would be to make a total extension at that edge of 4; but that would have the effect of putting the line D C at such an angle, that the point C would have gone down a distance of 3 below the point B, while the point D would therefore have gone up 3 above the point A, or 2 above the original zero line; so that while C was 4 below the zero line in extension, D was 2 above the zero line in compression; thus agreeing with Mr. Barlow's experiment, that with the weight applied at the extreme edge, the extension was double the compression.

Mr. W. Gravatt remarked, that it was astonishing what knowledge lay hidden in books. In Young's "Natural Philosophy," published in 1807, it was shown that by suspending the weight one-sixth of the width of a rectangular column from the centre it lost half its strength, and if it were hung on the edge, its strength was only one-fourth. Tredgold tried the experiment with perfect success.

Mr. W. H. Barlow said, Tredgold strained cast-iron plates along the line of the edge till the plates broke, at a strength of one-third of what it was in the middle.

Mr. Fleeming Jenkin thought the diagram with the springs referred to by Mr. Bramwell, represented what was given by the formula of the Author; at the same time he would mention, that there was some doubt whether iron could be looked upon as represented by an infinite number of small springs side by side. No doubt loading a column out of the centre of gravity of its section was treating it badly, and not giving it the work to do in the best way. This point lost much of its importance from the fact that the chief strains were the result of gradual accumulations from end to end, which, as had been worked out by Mr. Bramwell and Mr. Phipps, could not be distributed over the different parts of the section in the unequal manner supposed by the Author of the Paper. The bottom part of a boom could only be compressed more than the top by virtue of the bending of the boom, and the amount by which it was compressed, as compared with the top, would be indicated by the radius of curvature; therefore, unless considerable curvature was shown in that boom, it was impossible that one part could be compressed

more than another. There were only two ways in which the booms could bend, one was from end to end of the girder, and the total curvature of that way was small. Then there was another way in which the boom could be curved, as shown in Figs. 1 and 2, Plate 27, where there was a succession of inflections. Where that occurred it was clear the top and bottom of the boom alternately would be most compressed; while near the point of inversion of the curvature, the top and bottom would be equally compressed.

It was therefore impossible to allow that the accumulated result of the strains produced by each pair of diagonals was propagated from end to end of the girder, straining the bottom part more than the top in the proportion and manner indicated by the Author; on the contrary, the greatest strain sometimes was at the top and sometimes at the bottom, and the total strain of the 125 tons in the diagram would not be very unequally distributed over the central section of the boom.

Mr. G. H. Phipps begged to add a few words to his previous remarks:—He hoped that no one who had heard his views, either on the present or former occasions when this subject was discussed, would consider that he went anything like the length assumed by the Author of the Paper in respect to the degree of injurious action on the booms of girders attributable to the absence of coincidence of the lines of the compressive forces applied, and the neutral axes of the booms.

The Author's calculations (which he stated were confirmed by the demonstration of Professor Rankine), were only properly applicable to the case where the booms of girders might be supposed to consist of a number of pieces abutting upon, but detached from, each other at the points where the straining forces were successively brought on. Mr. Phipps had taken great care to point out, both in the discussion upon the Charing Cross Bridge as well as upon the present occasion, how largely the injurious action was mitigated by the booms being constructed in one continuous piece. On the former occasion, he had taken the distance of the line of compressive force from the neutral axis of the boom, as considerably less than the actual distance between those lines for the reasons then stated, and during the present discussion he had endeavoured to show more generally, that this diminution arose from the boom being thrown into a serpentine figure, having points of contrary flexure between each pair of the forces applied. That the boom might then be considered as divided into a number of parts separated at these points; and that all the forces which kept each detached part in repose being considered, their resultants would be found to depart from the axial lines of the booms a considerably less distance than that between the axis and line of the applied forces.

With regard to the interesting diagrams, and explanation given by Mr. Bramwell, the method adopted confirmed his own views, and, in fact, was identical in principle with the diagrams produced by him during the discussions upon the Charing Cross Bridge and upon American iron bridges.

Mr. W. H. Bidder said, he quite agreed with the views expressed in the Paper; but he could not say that he concurred with the Author in his subsequent remarks with respect to the attachment of lattice bars with the vertical plates of the flanges of lattice girders (a diagram of which was shown), as it appeared not to be in accordance with the views expressed in the Paper, viz., that of "uniform stress." He understood the Author to say that the lattice bars were in the best positions when their centre lines, if produced, would intersect each other at the lines of the centres of gravity of the top and bottom flanges, as the diagonal strains met at this point, and carried the horizontal strain along the centres of gravity of the flanges, thereby causing no detrimental action, but rather a uniformity of stress throughout the sections. But Mr. Bidder was of opinion, that the horizontal strain caused by the load on the diagonals took place at each of the rivets, separately and totally independently of each other; and that the vertical load carried by the rivets of the ties was transmitted horizontally to the rivets in the struts, and vice versâ. This tended to deflect the flanges into wave-lines, a deflection which was due to the moment of the weight on the tie-bar into the distance the rivets were apart, between the tie and strut, turning upon the rivets in the strut as a fulcrum in the top flange, and in the rivets of the ties as a fulcrum in the bottom flange. And if more than one rivet were used in the ends of the bars, there would be a tendency also to deflect the lattice bars into wave-lines, the top in one direction and the bottom in another. In his opinion, equilibrium could only be obtained by using one rivet only to unite the ends of the bars, and passing it through the centre of gravity of the flanges; but when more than one rivet was used, it would be better if the bars intersected each other at the centre of gravity of the riveting, that was if there was the same number of rivets above the intersection as there was below it. In that case, the tendency to deflect the flanges by the tension bars in one direction would be corrected by the tendency to deflect them in the opposite direction by the compression bars; but the line of pressure would still be as far from the centre of gravity of the flanges as the distance of the centre of gravity of the riveting was from it, and he would remark that the Author had obtained that object in the drawings of the bridges which he exhibited, viz., the intersection of the centre of gravity of the riveting of the diagonals with the centre of gravity of the flanges.

Mr. C. B. LANE remarked, it had been truly stated that a great deal of knowledge was to be got from books, and a great deal on the subject now under discussion was to be obtained in the library of the Institution. He would call the attention of the Members to an exhaustive Paper on the subject of lattice girders, read before the Institution about fourteen or fifteen years ago by Mr. W. B. Blood [1] and Mr. W. T. Doyne (M. Inst. C.E.). The concise and easily applied formula supplied therein justly entitled those gentlemen to be regarded with great consideration, as having contributed in the highest degree to the development of that form of structure. In making these remarks, he did not say one word in disparagement of the Paper now under discussion : on the contrary, he thought it a most able one, and many of the ideas insisted upon in it were very valuable.

Mr. POLE wished to add his testimony to the merit of the Paper, combining, as it did, intelligent theory with skilful practice. The Author had laid down a principle for adoption, and had followed that principle out, carefully and honestly, in all the details of the girders he had shown as examples. The principle of uniform stress was not a new one ; it had been submitted to calculation by Tredgold in his well-known book on cast iron, and his calculations had been checked experimentally by Eaton Hodgkinson. In the Paper the investigation had been carried further, and though the results obtained by theory might probably be modified by practical considerations (as was the case in almost all mathematical deductions), that did not at all detract from the value of the investigation. It demonstrated that a certain principle was advantageous, and that departure from it produced mechanical evils ; and it therefore warned Engineers to keep this principle in mind, and to approach it in practice as nearly as possible.

The Author had alluded incidentally to the difficulty of dealing with long struts or members under compressive strain. That was a point of much importance in large bridges, and as iron bridges of magnitude were now under consideration in various parts of the country, the treatment of them might form a good subject for discussion at the Institution.

Mr. PETER W. BARLOW said, the discussion had been directed to the point of the compression of the bars, the resistance being in the centre of gravity of compression ; and what had been said on that point was so clear, that it did not occur to him to make any observation upon it. But he would remark as to the comparison between the two systems of girders, that he had the impression in the first instance, he confessed, of there being an error in the calculation, to some extent. He had compared the Warren girder

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xi. p. 1.

with a girder of that description, and he found the advantages to be more than were stated by the Author. In other words, the figures would stand in the one case at 1,800 for the Warren, and in the other at 1,570. The impression of an error he had formed from looking at the diagrams. He found his calculations of the strains exactly agreed with the strains on the top, bottom, and verticals, but not on the diagonals; the impression he had was, that that accounted for the difference. He thought the subject would be more clearly understood if the figures on the diagonals expressed the actual strain, instead of its vertical component. He found, however, the difference in his calculation arose from the girder he had assumed being the Warren, having nine triangles; that described by the Author was not a Warren girder, in which the angles were 60°, and that made the difference between the two; he therefore agreed with the calculations of the Author assuming the same girders.

Mr. Callcott Reilly, in reply, said that, to some extent he agreed with the critical remarks made during the discussion, upon the extreme conclusions which had been put forward in the Paper. It had been argued that the great inequality in the distribution of the stress upon the section of a boom was much mitigated, towards the centre of the span, by the accumulated effect of the flexure, which was itself caused by that inequality, and he willingly confessed that he was of the same opinion, only, however, as regarded the condition of the compressed boom towards the centre of the span. The effect of flexure was expressly excluded from the data of the problem attempted to be solved in the Paper, partly to avoid the extreme complexity which would have embarrassed an argument already too complicated for easy comprehension. He had also long been aware that there were some Members who had made a special study of the effect of flexure in these cases, and he hoped that by putting forward the extreme results deduced in the Paper, he should thereby induce those Members to give the Institution the advantage of their knowledge in this department, and he felt gratified that he had succeeded in that object.

But, notwithstanding that the extreme inequality of the stress was probably much diminished in the top boom, towards the centre of the span, by the accumulated effect of flexure,—that accumulation being caused solely by the continuity of the boom at the web joints,—there were cases in which that effect could not occur, and in which therefore that extreme inequality would exist. That would be the case in the end-most bays of trusses formed like Nos. 1, 1 A, 2, and 2 A (Plate 27), because, in those divisions of the boom, flexure could not occur near the end-most joints, and as those trusses were without the excessively stiff end-pillars always applied to trusses formed like Nos. 1 B and 2 B, the effect of that

stiffness which had been contended for would not exist. In reference to that question of the stiffness of the end pillar, he confessed that he did not see his way to entire agreement in the conclusion arrived at, without a more exact demonstration than had been attempted. If the end-pillar and the diagonal tie were fastened to the trough-shaped top boom by a single pin, the argument in favour of that conclusion would of course fail, and indeed he did not gather that the conclusion had been intended to apply to such a case. Where the excessively stiff-end pillar existed, and was firmly fixed to the boom by riveting, no doubt the mitigation claimed by Mr. Heppel existed, more or less; but in any case the mitigation resulting from that cause would be difficult to calculate; and it did not, to his mind, seem a satisfactory thing, to depend either upon that, or upon the effect of flexure, to diminish the evil resulting from unequal distribution of the stress. Such dependence was unnecessary, and he thought quite inexpedient, as he had shown by the example of these two bridges, that no difficulty, either theoretical or practical, stood in the way of making all the important members of a truss conform to true scientific principle in this respect. But there were also other members of a truss which, as usually constructed, were liable to very unequal distribution of the stress: he alluded to the diagonal bars of the web, particularly to the struts. It was a common practice to make them of angle iron or T-shaped sections, either solid, or built up, and to place the rivets or bolts which connected them with the booms out of the centre of gravity of their cross sections. In such cases the inequality of the stress upon a cross section near to one of the joints in the struts, and under certain limitations anywhere in the ties, would be correctly calculated by the formula arrived at in the Paper, and it would truly represent the practical facts of the case, because there could be no accumulated effects of flexure to mitigate the inequality, such as had been contended for in the case of the booms. A remark had been made which suggested the inquiry, whether it was right to rivet or bolt together the diagonal bars of a triangular girder, such as No. 1 B or No. 2 B, at their intersections. If the bars and their joints with the booms were so arranged as to subject their sections only to a uniform stress, he was inclined to doubt it, because the deflection of the girder under its load would tend to draw the bars out of their originally straight lines; to put, in fact, a transverse strain upon them, if fastened together in the usual way, which would increase the stress upon one edge, and diminish it upon the other. But if the direct stress upon the bar were originally unequal, owing to the centre of gravity of the joint being out of the centre of gravity of the section of the bar, the fastening together of the bars at their intersection might be made beneficial, providing the cross

sections of the bars were so situated with respect to the centre of stress, that the flexure resulting from the deflection of the girder should be opposite to, and therefore tend to counteract, the flexure caused by the unequal distribution of the stress. If that condition were not attended to, of course the fastening at the intersections would only aggravate the evil caused by the unequal stress.

It had been argued that no unequal distribution of the stress upon a bar performing the function of a strut or a tie could take place without a corresponding flexure. That might be illustrated, as suggested by Mr. Bramwell, by supposing the bar to be confined in an exceedingly stiff tube, the effect of that restraint being entirely to prevent flexure taking place from the action of the unequally distributed stress, which would result from the application of an end-long force out of the axis of gravity of the bar; the result contended for was, that there being thus no flexure, there could be no inequality in the stress. If that illustration truly represented the opinion which had been advanced, he ventured to think the argument entirely untenable. It was opposed to the established doctrine of elasticity, which was simply, that the elastic material was shortened, or extended, as the case might be, in proportion to the amount of stress between its particles, providing that, if the stress was compression, room was allowed for the bulging of the material. Supposing, for instance, that the compressed boom of the truss, supporting a vertical load in the ordinary way, was confined between sufficiently rigid horizontal planes, the effect would be, to entirely prevent the vertical flexure contended for. But there would be no restraint upon the tendency to bulge (not bend) sideways, and the material being supposed to be elastic, and the compressive stress being unequally distributed, as in the case of a trough-shaped section, the horizontal fibres of the boom would be unequally shortened, and the unequal shortening of the fibres would be exactly proportional to the unequal longitudinal stress upon them. There would be no circumstance that could interfere with the free play of the law of elasticity; and under these conditions, the formula which had been deduced in the Paper from that law, and from nothing else, would accurately represent the state and amount of the stress upon any section of the boom, whether in the centre of the span, or elsewhere. The happy illustrations of the law of elasticity given by Mr. Bramwell, he thought entirely confirmed this conclusion.[1]

The next question was whether the unequal stress upon a trough-shaped lower boom, subject only to tension, was mitigated by the effect of flexure in the same manner and to the same extent as in

[1] *Vide ante*, pp. 439 to 443.

the case of the compressed boom. He believed this could not be, unless the inequality was so great that the tension entirely disappeared from one edge, and was replaced by more or less compression, the tension of the opposite edge being of course proportionately aggravated. In the former case, he thought, there would be no flexure and therefore no mitigation; in the latter case there would doubtless be flexure proportionate in some way to the amount of compression, and some mitigation would ensue, due to the same causes which had been explained during the discussion as operating in the case of the compressed boom. Therefore, he submitted, that the formula deduced in the Paper was applicable without qualification to the extended boom and the ties of a truss, except in the extreme case of the tension proper to the boom or tie-bar degenerating, so to speak, into partial compression.

In reference to the objections that had been raised to one of the propositions submitted in the Paper, viz., that the quantity of material required to give a certain constant degree of stiffness to a long strut, apart from that required to resist the mere compression, varied as the square of the length, the load being constant, he agreed with the arguments that had been used, but not with their application to the question under discussion. He thought they did not exactly apply to the question he had raised. He was himself, however, to blame for not having defined more precisely the limits of application of that proposition. He intended it to apply only to struts of the same figure, of uniform cross section, and of equal and uniform width, measured in the direction of the plane of the stiffening bracing. He did not deny that a trussed post, or a fish-bellied strut, would be more economical than the braced parallel struts usually put into truss girders, but the general use of the latter showed that they were more convenient. What he had intended to convey was, that in similar struts of equal width resisting the same compression, but differing in length, the quantity of material per unit of length, required to be put into the strut to resist the stress due to bending, and thereby secure a certain constant degree of stiffness, varied as the square of the length, whether that additional material was an addition to the uniform sectional area of the strut, or to the weight of the bracing, or to both. That proposition he believed to be true, because it was an easy inference from the theorem deduced by Mr. Lewis Gordon from Hodgkinson's experiments on long pillars, and quoted in Professor Rankine's "Applied Mechanics." If then, the weight, per unit of length, of the stiffening material varied as the square, the weight per strut must vary as the cube of its length. He agreed with Mr. Phipps, that the proper place for additional stiffening material was the solid section of the strut, not the cross bracing only. To show, however, that the theory did not lead to extravagant results,

even when the increase was confined to the bracing, he had calculated the dimensions of the stiffening bracing required by the cube theory to be applied to the struts of the truss No. 1 B, the load being supposed the same as in No. 1. The details of that calculation were exhibited in one of the explanatory foot-notes[1] to the Paper, and the result was that the 42·2 units of weight, assigned to the stiffening in the comparison between the trusses,[2] would be equivalent to the weight of the halves of four vertical angle irons, each $2\frac{1}{2}$ inches by $\frac{5}{16}$ inch, and one set of flat bracing bars, each $2\frac{3}{4}$ inches wide by $\frac{3}{8}$ inch thick, crossing each other in pairs, and arranged in a manner precisely similar to that exhibited in the drawings of No. 1 truss. Those proportions were, to say the least, certainly not greater than would be warranted by the current practice of the day. He therefore ventured to think that his argument, within the limits of its application, in favour of the economy of the vertical strut over the inclined one, was not shaken by the remarks which had been made; at the same time, he thought the ideas which had been expressed were valuable and useful, although not exactly applicable as an answer to the proposition submitted in the Paper. But even admitting that the cube theory was untenable, and supposing that the doubtful question of stiffening was eliminated from the comparisons between the different trusses given in the Paper, No. 2 truss would still be lighter than either of the others, and No. 1 would be about 1 per cent. lighter than No. 1 B, but about $2\frac{1}{2}$ per cent. heavier than No. 1 A; so that, on the whole, and under the most unfavourable suppositions, the trusses with vertical struts were not less economical than the best of those with struts inclined.

The opinion had been expressed that No. 2 truss was an imperfect truss, because the diagonal bars attached at the loaded joints of the girder were directed towards one pier only, whereas it was contended, that diagonals were required to extend from each loaded joint towards both piers. That opinion implied, in fact, that the loads could not be transmitted from each loaded joint, in due proportion to the two points of ultimate support at the piers, without the intervention of two sets of diagonals, and that the upright bars were of no use for that purpose. Now he ventured to say that most persons, who understood this subject, knew that every framework composed entirely of triangles securely connected at the angles, was a perfect truss in a statical sense. Of course some combinations of triangles would form trusses objectionable, because wasteful of material, or because liable to undue deflection or vibration. But those could not be the grounds of the objection

[1] *Vide* footnote, p. 400.

[2] *Vide* p. 402.

to the bridges described in the Paper, for so far as at present known,[1] both the deflection and vibration were unusually small, and as to economy of material, the weights and strengths, which had been fully described, would speak for themselves.[2] Of course the upright bars of the web did their share of the duty which had to be performed by the web as a whole, and transmitted their due proportion of load to the piers. Additional diagonals would only be an incumbrance and a waste of material. If two sets of diagonals were used, the vertical bars would not be wanted, as exemplified in trusses Nos. 1 B and 2 B.[3]

The principal views supported and illustrated in the Paper had been directly and entirely opposed by the argument that for a moderate span the T shape was the best section for the booms, both theoretically and practically. It would be admitted that every objection that could be raised against the trough applied with at least equal force to the T-shaped section. For a plate girder or a tubular girder with solid plate sides continuously joined by close riveting to the booms, no doubt it might reasonably be argued, that the T shape and the trough the shape were the most suitable forms of section for the booms. But, as regarded the questions which had been discussed, there was no analogy between such girders and open work-trusses, such as were exhibited by the diagrams in Plate 27. In solid-sided girders the deflection line would be a continuous curve, and the greatest stress would be at the greatest distance from the general neutral axis of the girder, and therefore the greatest mass of resisting material would

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[1] Since this discussion took place both bridges have been officially tested with the following results:—

No. 1 was tested by a heavy locomotive and tender, and train of loaded trucks. In running backwards and forwards over the bridge the greatest deflection observed was half an inch, and there was no perceptible vibration. The weight of this load had not been reported up to the time of going to press, but Mr. E. H. Woods, the Chief Resident Engineer to the Company, who superintended the erection of the bridge, reported the result to be entirely satisfactory.

No. 2 was tested by Colonel Yolland, by a train of two of the heaviest goods engines and tenders belonging to the Brighton Railway Company. The greatest deflection observed was a quarter of an inch; and there was absolutely no vibration perceptible in any part of the girders when the train run at speed over the bridge. The intensity of the moving test load, in this instance, slightly exceeded 1½ ton per foot of span, the railway being a single line.

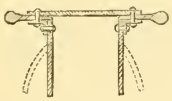
[2] *Vide* p. 394.

[3] It may be as well to remark, in reference to this point, that all the ties and struts, except the endmost ones, are subject to both tensile and compressive stress, the difference between them being that in the ties the tension exceeds the compression, in the struts, the compression exceeds the tension, the resultants being in the former case, tension, in the latter, compression. But towards the centre of the span, the greatest compression upon the ties produced by the heavy travelling load exceeds the tension caused by the fixed load, requiring therefore that these ties be stiffened, so as to act as struts. In like manner, the travelling load converts the central struts into ties.

be properly accumulated at the extreme top and bottom. But the case was otherwise with open trusses in which, while the continuous deflection curve coincided with the curve of the booms at the joints only, each bar both of the booms and web was liable to a special deflection, on its own account so to speak, often quite contrary to that which occurred in a solid beam. That was shown in the course of the discussion, for whereas the opposite view was, that in the top boom the curve of deflection was always concave upwards, as in the solid beam, Mr. Phipps's diagram showed that it was a curve of contrary flexure, most of it apparently convex upwards.

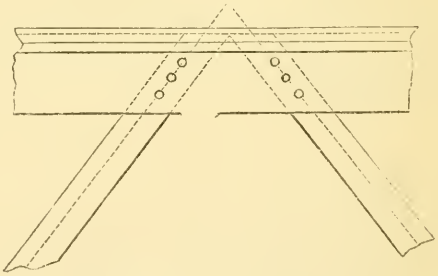
It had been asserted, as a reason for preferring the trough-shaped or T-shaped section of boom, that failure of the top boom would begin at the extreme top surface. On that point, he had been favoured by Messrs. Kennard Brothers, with some particulars of a test that was applied some years ago to a pair of diagonal trusses of the same class as No. 2 B, for a single line railway bridge in Italy, which in its result directly negatived that assertion. The trusses were of 135 feet span, the top boom and the joint of the diagonals with it were shown in Figs. 18 and 19.

Fig. 18.



Cross Section, the dotted lines indicating the effect of the buckling which took place.

Fig. 19.



Part Elevation of Top Boom.

A load of the intensity of 1 ton per foot of span was applied, in addition to the weight of the structure. Such a load would certainly not exceed the possible working load, and the nominal stress produced by it, if erroneously assumed to be equally distributed, was not more than 4 tons per square inch of compression. The effect of that very moderate load was first to buckle the vertical sides of the top boom, close to the joints of the diagonal bars, then to buckle the diagonals, and after that the end pillar. In justice to Messrs. Kennard it should be known that they were not consulted in the design of these girders, which was the work of an Italian Engineer. Since that experiment they had adopted the practice of putting stiffening blocks between the sides of the

trough to obviate the effect of buckling, but of course the use of those blocks, while adding to the dead weight, did not diminish the inequality of the stress.

It had been said, that a double web was unnecessary in girders of such comparatively small span as those exhibited. He thought in opposition to that view, that a certain degree of lateral stiffness could be given, to even small span trusses, by the use of a double web, united by no more than sufficient stiffening bracing, with less weight of material than by any other mode of construction. That opinion he thought was sufficiently justified by the economy of material in the two bridges described in the Paper.[1]

In reference to what had fallen from Mr. Lane, Mr. Reilly entirely concurred in that gentleman's high opinion of the Paper, on the nature and mode of calculation of the stresses upon lattice girders, contributed to the Minutes of Proceedings of the Institution by Mr. Doyne and Mr. Blood. The earliest information he had acquired on the subject of lattice girders had been obtained from a study of that Paper many years ago. But he thought it a mistake to characterize it as exhaustive of the subject; on the contrary, the labours of Professor Rankine, Mr. John Herbert Latham and others, to say nothing of continental writers, had since then given a greater breadth and depth to the current knowledge of this subject. Moreover, the Paper alluded to did not touch upon the special subject which he had been permitted to submit to the Institution.

Mr. W. H. Bidder had made some valuable remarks, which Mr. Reilly thought required no answer from him, because he was pleased to find that they were very much in conformity with his own views.

Mr. Reilly concluded by thanking the Members for the kind reception, and patient attention which had been given to the Paper, and also those speakers whose careful arguments had lent so much interest to the discussion.

May 2 and 9, 1865.

JOHN FOWLER, Vice-President,
in the Chair.

The discussion upon the Paper No. 1,110, "On Uniform Stress in Girder Work," occupied both evenings, to the exclusion of any other subject.

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[1] The entire absence of vibration in these bridges, the Author suggests, is corroborative of this opinion, and a justification of the mode of construction contended for in the Paper.

The following Candidates were balloted for and duly elected on May 2nd:—His Grace the Duke of Sutherland, K.G., as an Honorary Member, George Black, John Calvert, John Coghlan, Francis Mackison, and Philip William Wall, as Members; Patrick Adie, Thomas Alexander James Brend Batten, Alfred Clayton, Arthur Folkard, William Fox, Thomas Arthur Greenhill, Walter Hunter, John Henry Johnson, Baldwin Latham, John Morgan, John Napier, and Charles Rolfe, as Associates.

May 16, 1865.

JOHN ROBINSON M'CLEAN, President,
in the Chair.

No. 1,122.—"On the Maintenance of Railway Rolling Stock."[1]

By EDWARD FLETCHER.

As the subject of the maintenance of Railway Rolling Stock is one of great importance to the railway community, the Author has been induced to submit, for the consideration of the Members of this Institution, the statistics of the rolling stock belonging to the North-Eastern Railway Company. The rolling stock is divided under four distinct heads, viz.:—Locomotive Engines, Carriages, Merchandize Wagons, and Chaldron Coal Wagons; and the Carriages and Merchandize Wagons are again subdivided into separate classes,—all of which have been tabulated, and summary tables are likewise given in the Appendix.

The tables are made up at annual periods, and extend over thirteen years, from 1852 to 1864 inclusive. They have been arranged with the view of showing, in a comprehensive form, the ages of the different classes of stock, and the average of the whole. It is submitted, that if the average age of all the stock does not exceed one-half the number of years which may be found by experience to be a fair average of the existence, or life, of the stock, then justice is done to the stock in maintenance. Another object has been to show what per centage the annual expenditure in maintenance bears to the first cost of the stock. It is believed, that these tables, if kept up with care, will in a few years, be the means of affording to the Directors of any Railway good data for checking the annual expenditure, and for forming a correct opinion as to the sufficiency, or insufficiency of the maintenance. They likewise show the cost of maintenance of each vehicle per annum; and in the case of locomotive engines, the cost per mile run.

The Author knows how difficult it is to persuade the locomotive and carriage superintendents of the different railways to adopt a uniform system of accounts, and that the circumstances of different railways vary considerably. At the same time, he is certain that if the principal railway companies could prepare

[1] The discussion upon this Paper occupied portions of two evenings, but an abstract of the whole is given consecutively.

similar returns, some grounds for comparison would be at once obtained, as these tables do not represent opinions, but facts.

After giving this question of the ultimate age of rolling stock his best consideration, he is of opinion that the improved rolling stock of the present day—built of carefully-selected and well-seasoned timber, and of other materials of the best quality—superior in all respects to that built twenty years ago—may be fully calculated to have a life of from twenty-five years to thirty years;—assuming always, that the stock is of such a character that it will not be necessary to break it up for any other cause than that of decay.

It is also to be remarked, that on all large railways, the quantity of rolling stock is always increasing, the result of which is, to keep down the average age of the stock; and there being a large amount of new stock on which little expenditure is required for some years, the per centage of outlay is proportionably diminished. Making allowances on these points, the conclusion has been arrived at, that carriage stock may be fully maintained by an outlay of about 12 per cent. on its cost, wagon stock by an outlay of $6\frac{1}{2}$ per cent., and locomotive stock by an outlay of $12\frac{1}{2}$ per cent.

The chaldron wagon stock is peculiar to the North of England. These wagons have generally cast-iron wheels, are without springs, and are liable to great breakage by inclined planes and other hard usage; and hence arises the fact that, whereas the general wagon stock only costs $6\frac{1}{2}$ per cent. on its first cost for maintenance, this chaldron wagon stock costs $17\frac{1}{2}$ per cent. The use of this stock is by degrees being discontinued, and its place is being supplied by 8-ton wagons of superior construction. An 8-ton coal-wagon costs £90, and three chaldron wagons, to carry the same quantity of coals, £75; but the cost of maintenance in the first case would be only £5 10s., whilst in the second, it would amount to £13, showing that the superior wagon is the cheaper one of the two.

The number of locomotive engines belonging to the Company at the end of 1864 was 504, and the average age of them 12·48 years. If it be assumed that the duration of an engine is 25 years, then the Company should have been rebuilding at the rate of twenty engines annually, to be paid for out of revenue, in order to keep the stock up to its original value; but the table shows, that for the last five years, only eleven engines have, on an average, been rebuilt annually. But in the column representing the total number rebuilt during the year, only those engines are included which have been entirely new, and of a different class when rebuilt. When an engine has had a new boiler, and has been entirely otherwise renewed, it has not been included as being rebuilt, if rebuilt of the same class. Therefore taking into account

all the engines rebuilt, including those of the same class, the total number has been twenty per annum. Of the engines that have been rebuilt the greater number were old when they came into the possession of the Company.

The following statement shows the total number of the different descriptions of stock, and the average age of each at the end of the year 1864. It also gives the average cost of repairing per vehicle per annum, and the per centage of repairs, and rebuilding on the first cost for the thirteen years from 1852 to 1864:—

Description.	Total Number.	Average Age.	Cost of Repairing and Rebuilding, per Vehicle per Annum.	Per Centage of Repairs and Rebuilding on Total Cost.	Per Centage of Rebuilding on Total Cost.	Cost per Mile for Repairing and Upholding.	Cost per Mile for Extraordinary Repairs, included under "Repairs and Upholding."
		Years.	£. s. d.	£.	£.	d.	d.
Locomotive Engines .	504	12·48	..	12·55	..	2·95	1·92
Carriages.	1,370	9·75	22 0 9	11·26	4·46	..	..
Wagons	17,429	10·31	4 8 4	6·39	2·89	..	..
Chaldron Coal Wagons.	11,872	..	2 15 0	17·42	..	..	..

NORTH EASTERN RAILWAY.

Ages of First Class Carriages.

DATES.	YEARS.																								Total Rebuilt in the Half-Year.	Total Number of Stock.	Average Age in Years.
	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
1852	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	38	..	4	6	7	21	8	5	..	..	..	89	7·28
1853	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	46	2	5	41	18	30	15	5	2	3	3	..	170	7·73
1854	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	45	2	5	41	18	30	15	5	2	3	3	6	1	176	8·40
1855	..	..	..	..	..	..	..	..	..	..	..	..	..	..	45	2	5	41	18	30	15	5	2	3	3	7	20	..	196	8·55
1856	..	..	..	..	..	..	..	..	..	..	..	..	..	40	1	5	41	18	30	15	5	2	3	3	7	20	..	6	196	9·15
1857	..	..	..	..	..	..	..	..	..	..	..	..	35	1	5	41	18	28	15	5	2	3	3	7	20	6	..	7	196	9·76
1858	..	..	..	..	..	..	..	..	..	..	..	32	1	4	40	17	28	14	5	2	3	3	7	20	6	7	..	7	196	10·25
1859	..	..	..	..	..	..	..	..	..	..	27	1	3	40	15	28	13	5	1	3	3	7	20	6	7	7	..	10	196	10·55
1860	..	..	..	..	..	..	..	..	..	23	1	3	33	15	26	12	5	1	3	3	7	20	6	7	7	10	..	14	196	10·53
1861	..	..	..	..	..	..	..	..	22	1	3	30	14	26	11	5	1	3	3	7	20	6	7	7	10	14	4	6	200	10·87
1862	..	..	9	..	..	..	..	6	1	3	30	14	26	11	5	1	3	3	7	20	12	8	7	11	14	10	..	16	217	11·38
June, 1863	..	9	..	..	..	..	..	1	3	30	14	26	11	5	1	3	3	7	20	12	8	7	11	14	10	16	1	6	218	11·22
Dec., 1863	..	9	..	..	..	..	..	..	3	30	11	24	11	5	1	3	3	7	20	12	8	7	11	14	10	16	7	6	218	10·77
June, 1864	9	..	..	..	..	..	..	3	29	10	22	9	5	1	3	3	7	20	12	8	7	11	14	10	16	13	..	6	218	11·33
Dec., 1864	8	..	..	..	..	..	..	3	28	9	22	8	5	1	3	3	7	20	12	8	7	11	14	10	16	13	6	4	218	10·98

Remarks.—Up to June, 1863, only those Carriages are included in the Column as having been *rebuilt* which have been entirely new.
In 1862 the Stocks of the Hull and Holderness, and Newcastle and Carlisle Railways are included.

NORTH EASTERN RAILWAY.

Ages of Composite Carriages.

DATES.	YEARS.																										Total Rebuilt in the Half-Year.	Total Number of Stock.	Average Age in Years.
	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
1852	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	29	..	..	..	..	..	..	..	3	1	..	..	..	33	10·00
1853	..	..	..	..	..	..	..	..	..	..	..	..	..	..	43	1	..	1	..	1	..	..	6	4	4	7	5	..	72	9·25
1854	..	..	..	..	..	..	..	..	..	..	..	..	..	43	1	..	1	..	1	..	..	6	4	4	7	5	7	..	79	9·43
1855	..	..	..	..	..	..	..	..	..	..	..	..	40	1	..	1	..	1	..	..	6	4	4	7	5	7	..	3	79	9·89
1856	..	..	..	..	..	..	..	..	..	..	..	32	1	..	1	..	1	..	..	6	4	4	7	5	7	3	..	8	79	9·37
1857	..	..	..	..	..	..	..	..	..	..	30	1	..	1	..	1	..	..	6	4	4	7	5	7	3	8	..	2	79	9·97
1858	..	..	..	..	..	..	..	..	..	27	1	..	..	..	1	..	..	5	4	4	6	5	7	3	8	2	..	6	79	9·96
1859	..	..	..	..	..	..	..	..	22	..	..	..	..	1	..	..	5	4	4	5	5	7	3	8	2	6	..	7	79	9·52
1860	..	..	..	..	..	..	..	18	..	..	..	..	1	..	..	5	3	4	2	4	6	3	8	2	6	7	..	10	79	8·96
1861	..	..	..	..	..	..	12	..	..	..	..	1	..	..	2	3	4	2	4	6	3	8	2	6	7	10	6	9	85	7·49
1862	..	..	5	..	..	12	..	..	..	..	1	..	..	2	3	4	2	4	7	3	8	2	6	7	10	15	2	..	93	9·22
June, 1863	..	5	..	..	12	..	..	..	..	1	..	..	2	3	4	2	4	7	3	8	2	6	7	10	15	2	12	..	105	9·17
Dec., 1863	..	5	..	..	12	..	..	..	..	1	..	..	2	3	4	2	4	7	3	8	2	6	7	10	15	2	12	..	105	9·17
June, 1864	5	..	..	12	..	..	..	..	1	..	..	2	3	4	2	4	7	3	8	2	6	7	10	15	2	12	9	..	114	9·44
Dec., 1864	4	..	..	12	..	..	..	..	1	..	..	2	3	3	2	4	7	3	8	2	6	7	10	15	2	12	24	2	129	8.16

Remarks.—Up to June, 1863, only those Carriages are included in the Column as having been *rebuilt* which have been entirely new.
In 1862 the Stocks of the Hull and Holderness, and Newcastle and Carlisle Railways are included.

NORTH EASTERN RAILWAY.

Ages of Second Class Carriages.

DATES.	YEARS.																								Total Rebuilt in the Half-Year.	Total Number of Stock.	Average Age in Years.
	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
1852	..	..	..	..	..	..	..	..	..	..	..	..	..	..	45	..	..	..	1	4	11	28	34	..	7	..	..	130	7·17
1853	..	..	..	..	..	..	..	..	..	..	..	..	..	94	..	..	3	..	16	16	33	36	..	1	12	2	..	213	8·91
1854	..	..	..	..	..	..	..	..	..	..	..	..	84	..	..	3	..	16	16	33	36	..	1	12	2	..	10	213	9·30
1855	..	..	..	..	..	..	..	..	..	..	..	76	..	..	3	..	16	16	33	36	..	1	12	2	10	..	8	213	9·77
1856	..	..	..	..	..	..	..	..	..	..	66	..	..	3	..	16	16	33	36	..	1	12	2	10	8	..	10	213	10·07
1857	..	..	..	..	..	..	..	..	..	61	..	..	3	..	15	16	32	36	..	1	12	2	10	8	10	..	7	213	10·60
1858	..	..	..	..	..	..	..	..	56	..	..	3	..	15	15	32	36	..	1	4	2	10	8	10	7	..	14	213	10·92
1859	..	..	..	..	..	..	..	51	..	..	3	..	15	13	31	36	..	1	2	2	10	8	10	7	14	..	10	213	11·32
1860	..	..	..	..	..	..	40	..	..	2	..	15	11	28	36	..	1	2	2	10	8	10	7	14	10	..	17	213	10·92
1861	..	..	..	..	..	35	..	..	1	..	14	10	27	33	..	1	2	2	10	8	10	7	14	10	17	1	12	214	10·96
1862	..	11	..	..	31	..	..	1	..	14	10	27	33	..	2	3	3	12	9	12	11	14	10	17	14	..	4	238	11·97
June, 1863	11	..	..	22	..	..	1	..	14	10	27	33	..	2	3	3	12	9	12	11	14	10	17	14	4	..	9	238	12·14
Dec., 1863	4	..	..	22	..	..	1	..	14	7	27	33	..	2	3	3	12	9	12	11	14	10	17	14	4	9	10	238	11·20
June, 1864	..	..	16	..	..	1	..	13	6	24	31	..	2	3	3	12	9	12	11	14	10	17	14	4	19	12	17	250	10·25
Dec., 1864	..	..	14	..	..	1	..	13	6	21	28	..	2	3	3	12	9	12	11	14	10	17	14	4	19	29	8	250	9·69

Remarks.—Up to June, 1863, only those Carriages are included in the Column as having been *rebuilt* which have been entirely new.
In 1862 the Stocks of the Hull and Holderness, and Newcastle and Carlisle Railways are included.

NORTH EASTERN RAILWAY.

Ages of Third Class Carriages.

DATES.	YEARS.																								Total Rebuilt in the Half-Year.	Total Number of Stock.	Average Age in Years.
	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
1852	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	39	..	..	..	8	..	18	12	2	..	..	..	..	79	8·96
1853	..	..	..	..	..	..	..	..	..	..	..	..	..	..	7	..	..	..	5	2	49	25	12	1	2	5	81	..	189	4·58
1854	..	..	..	..	..	..	..	..	..	..	..	..	..	41	..	..	..	5	2	49	25	12	1	2	5	81	16	..	239	6·22
1855	..	..	..	..	..	..	..	..	..	..	..	..	30	..	..	..	2	2	46	24	12	1	2	5	81	16	..	18	239	6·32
1856	..	..	..	..	..	..	..	..	..	..	..	24	..	..	..	2	2	43	24	12	1	2	5	80	16	17	..	11	239	6·81
1857	..	..	..	..	..	..	..	..	..	..	20	..	..	..	2	2	30	19	12	1	2	5	80	16	17	11	..	22	239	6·81
1858	..	..	..	..	..	..	..	..	..	19	..	..	..	2	2	30	19	12	1	2	5	80	16	17	11	22	40	1	279	6·77
1859	..	..	..	..	..	..	..	..	18	..	..	..	2	2	30	19	12	1	2	5	80	16	17	11	22	41	..	1	279	7·71
1860	..	..	..	..	..	..	..	18	..	..	..	2	1	30	19	12	1	2	5	80	16	17	11	22	41	1	..	1	279	8·66
1861	..	..	..	..	..	..	17	..	..	..	2	..	30	17	12	..	2	4	80	16	17	11	22	41	1	1	25	6	304	8 68
1862	..	..	26	..	..	11	..	..	..	2	..	30	17	12	..	2	5	80	17	20	28	22	44	3	2	33	22	7	383	9·61
June, 1863	..	26	..	..	9	..	..	..	2	..	30	17	12	..	2	5	80	17	20	28	22	44	3	2	33	29	..	2	383	10·50
Dec., 1863	..	25	..	..	9	..	..	..	2	..	27	14	12	..	2	5	79	15	20	28	22	44	3	2	33	29	2	10	383	10·12
June, 1864	24	..	..	9	..	..	..	2	..	27	14	12	..	2	5	79	15	20	28	22	44	3	2	33	29	12	..	1	383	11·05
Dec., 1864	20	..	..	9	..	..	..	2	..	26	14	12	..	2	5	79	9	20	28	22	44	3	2	33	29	12	13	11	395	10·29

Remarks.—Up to June, 1863, only those Carriages are included in the Column as having been *rebuilt* which have been entirely new.
In 1862 the Stocks of the Hull and Holderness, and Newcastle and Carlisle Railways are included.

NORTH EASTERN RAILWAY.

Ages of Luggage and Parcels Vans.

DATES.	YEARS.																				Total Rebuilt in the Half-Year.	Total Number of Stock.	Average Age in Years.
	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
1852	..	..	..	..	..	..	..	..	..	..	..	..	4	2	2	12	6	..	..	..	..	26	5·46
1853	..	..	..	..	..	..	..	..	..	..	..	68	..	4	12	1	1	5	6	8	..	105	7·20
1854	..	..	..	..	..	..	..	..	..	..	68	..	4	12	1	1	5	6	8	28	..	133	6·68
1855	..	..	..	..	..	..	..	..	..	64	..	4	12	1	1	5	6	8	28	12	4	145	6·86
1856	..	..	..	..	..	..	..	..	60	..	4	11	1	1	5	6	8	28	16	..	5	145	7·40
1857	..	..	..	..	..	..	..	59	..	4	10	1	1	5	6	8	28	16	5	..	2	145	8·35
1858	..	..	..	..	..	..	55	..	4	10	1	1	5	6	8	28	16	5	2	..	4	145	8·99
1859	..	..	..	..	..	49	..	4	10	1	1	5	6	8	28	16	5	2	4	10	6	155	8·87
1860	..	..	..	..	39	..	4	10	1	1	5	6	8	28	16	5	2	4	16	..	10	155	8·89
1861	..	..	..	38	..	4	9	1	1	5	6	8	28	16	5	2	4	16	10	14	2	169	8·99
1862	..	..	17	..	4	9	1	1	5	7	17	30	18	7	3	4	16	11	16	9	13	188	7·93
June, 1863	..	9	..	4	9	1	1	5	7	17	30	18	7	3	4	16	11	16	22	..	8	188	8·16
Dec., 1863	..	9	..	4	8	1	1	5	6	13	29	17	7	3	4	16	11	16	22	8	8	188	7·72
June, 1864	7	..	4	6	..	1	5	6	13	29	17	7	3	4	16	11	16	22	16	10	5	198	7·90
Dec., 1864	4	..	4	5	..	1	5	6	13	29	17	6	3	4	16	11	16	22	16	22	5	205	7·27

Remarks.—Up to June, 1863, only those Carriages are included in the Column as having been *rebuilt* which have been entirely now. In 1862 the Stocks of the Hull and Holderness, and Newcastle and Carlisle Railways are included.

NORTH EASTERN RAILWAY.

Ages of Horse Boxes.

DATES.	YEARS.																									Total Rebuilt in the Half-Year.	Total Number of Stock.	Average Age in Years.
	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
1852	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	15	..	..	..	..	10	3	7	..	..	..	..	..	35	8·65
1853	..	..	..	..	..	..	..	..	..	..	..	..	..	..	17	15	..	..	..	10	14	6	..	2	11	3	..	1	79	8·39
1854	..	..	..	..	..	..	..	..	..	..	..	..	..	17	14	..	..	..	1	14	6	..	2	11	3	1	..	10	79	8·33
1855	..	..	..	..	..	..	..	..	..	..	..	..	17	14	..	..	..	1	14	6	..	2	11	3	1	10	..	..	79	9·32
1856	..	..	..	..	..	..	..	..	..	..	..	16	14	..	..	..	1	14	4	..	2	11	3	1	10	..	..	3	79	9·93
1857	..	..	..	..	..	..	..	..	..	..	15	14	..	..	..	1	14	4	..	2	11	3	1	10	..	3	..	1	79	10·73
1858	..	..	..	..	..	..	..	..	..	13	14	..	..	..	1	13	4	..	2	11	3	1	10	..	3	1	20	3	99	9·11
1859	..	..	..	..	..	..	..	..	12	14	..	..	..	1	11	1	..	2	11	3	1	10	..	3	1	23	..	6	99	9·35
1860	..	..	..	..	..	..	..	9	14	..	..	..	1	11	1	..	2	11	3	1	10	..	3	1	23	6	..	3	99	9·77
1861	..	..	..	..	..	..	9	14	..	..	..	1	11	1	..	2	11	3	1	10	..	3	1	23	6	3	..	..	99	10·77
1862	..	..	10	..	..	5	14	..	..	..	1	11	1	..	2	11	3	1	10	..	3	2	23	8	3	..	..	4	112	12·01
June, 1863	..	10	..	..	..	11	..	..	..	1	11	1	..	2	11	3	1	10	..	3	2	23	8	3	..	4	..	8	112	11·47
Dec., 1863	..	9	..	..	..	11	..	..	..	1	8	1	..	2	11	3	1	10	..	3	2	23	8	3	..	4	8	4	112	10·83
June, 1864	9	..	..	..	11	..	..	..	1	6	1	..	2	11	3	1	10	..	3	2	23	8	3	..	4	12	..	2	112	11·51
Dec., 1864	9	..	..	..	11	..	..	..	1	6	1	..	2	11	3	1	10	..	3	2	23	8	3	..	4	12	2	..	112	11·51

Remarks.—Up to June, 1863, only those Carriages are included in the Column as having been *rebuilt* which have been entirely new.
In 1862 the Stocks of the Hull and Holderness, and Newcastle and Carlisle Railways are included.

NORTH EASTERN RAILWAY.

Ages of Carriage Trucks.

DATES.	YEARS.																									Total Rebuilt in the Half-Year.	Total Number of Stock.	Average Age in Years.
	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
1852	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	15	..	..	..	10	..	3	..	..	..	..	..	28	8·92
1853	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	39	..	..	4	..	2	..	..	2	1	3	1	..	52	10·30
1854	..	..	..	..	..	..	..	..	..	..	..	..	..	..	38	..	..	4	..	2	..	..	2	1	3	1	..	1	52	11·10
1855	..	..	..	..	..	..	..	..	..	..	..	..	..	36	..	..	4	..	2	..	..	2	..	3	1	1	..	3	52	11·50
1856	..	..	..	..	..	..	..	..	..	..	..	..	35	..	..	4	..	2	..	..	2	..	3	1	1	3	..	1	52	12·04
1857	..	..	..	..	..	..	..	..	..	..	..	27	..	..	4	..	2	..	..	2	..	3	1	1	3	1	..	8	52	10·92
1858	..	..	..	..	..	..	..	..	..	..	25	..	..	4	..	2	..	..	2	..	2	1	1	3	1	8	..	3	52	11·18
1859	..	..	..	..	..	..	..	..	..	25	..	..	4	..	2	..	..	2	..	2	1	1	3	1	8	3	..	..	52	11·88
1860	..	..	..	..	..	..	..	..	25	..	..	4	..	2	..	..	2	..	2	1	1	3	1	8	3	..	..	..	52	12·88
1861	..	..	..	..	..	..	..	25	..	..	4	..	2	..	..	2	..	2	1	1	3	1	8	3	..	..	..	..	52	13·88
1862	..	..	7	..	..	..	10	..	..	4	..	2	..	..	2	..	2	1	1	3	1	8	3	..	..	..	..	17	61	10·93
June, 1863	..	7	..	..	..	5	..	..	4	..	2	..	..	2	..	2	1	1	3	1	8	3	..	..	..	17	..	5	61	10·21
Dec., 1863	..	7	..	..	..	5	..	..	4	..	2	..	..	2	..	2	1	1	3	1	8	3	..	..	..	17	5	..	61	10·21
June, 1864	6	..	..	..	5	..	..	4	..	2	..	..	2	..	2	1	1	3	1	8	3	..	..	..	..	17	5	..	1	61	10·78
Dec., 1864	6	..	..	..	5	..	..	4	..	2	..	..	2	..	2	1	1	3	1	8	3	..	..	..	..	17	5	1	..	61	10·78

Remarks.—Up to June, 1863, only those Carriages are included in the Column as having been *rebuilt* which have been entirely new.
In 1862 the Stocks of the Hull and Holderness, and Newcastle and Carlisle Railways are included.

NORTH EASTERN RAILWAY.

Ages of Goods Break Vans.

Dates.	Years.																			Total Rebuilt in the Half-Year.	Total Number of Stock.	Average Age in Years.
	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
1852	..	..	..	..	..	..	..	..	..	12	..	8	..	..	..	..	.	..	..	..	20	9·20
1853	..	..	..	..	..	..	..	..	12	..	8	..	4	6	4	4	4	10	8	2	62	5·58
1854	..	..	..	..	..	..	..	12	..	8	..	4	6	4	4	4	10	10	36	..	98	4·53
1855	..	..	..	..	..	..	12	..	8	..	4	6	4	4	4	10	10	36	..	..	98	5·53
1856	..	..	..	..	..	12	..	8	..	4	6	4	4	4	10	10	36	..	..	..	98	6·53
1857	..	..	..	..	11	..	8	..	4	6	4	4	4	10	10	36	..	..	6	1	104	7·01
1858	..	..	..	11	..	8	..	4	6	4	4	4	10	10	36	..	..	7	..	..	104	8·01
1859	..	..	11	..	8	..	4	6	4	4	4	10	10	36	..	..	7	..	2	..	106	9·03
1860	..	9	..	8	..	4	6	4	4	4	10	10	36	..	..	7	..	2	4	2	110	9·23
1861	8	..	8	..	4	6	4	4	4	10	10	36	..	..	7	..	2	6	32	1	142	8·02
1862	..	..	..	..	4	4	4	4	11	11	47	4	2	9	2	5	6	36	19	11	179	6·25
June, 1863	..	..	..	..	4	4	4	11	11	47	4	2	9	2	5	6	36	30	6	4	185	6·73
Dec., 1863	..	..	..	..	3	4	4	9	11	44	4	2	9	2	5	6	36	30	11	6	186	6·42
June, 1864	..	..	..	3	4	4	9	11	44	4	2	9	2	5	6	36	30	17	21	..	207	6·71
Dec., 1864	..	..	..	3	4	4	7	10	41	4	2	9	2	5	6	36	30	17	54	6	240	5·65

Remarks.—Up to June, 1863, only those Wagons are included in the Column as having been *rebuilt* which have been entirely new. In 1862 the Stocks of the Hull and Holderness, and Newcastle and Carlisle Railways are included.

NORTH EASTERN RAILWAY.

Ages of Stores Vans.

DATES.	YEARS.																			Total Rebuilt in the Half-Year.	Total Number of Stock.	Average Age in Years.
	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
1852	..	..	..	..	..	..	..	..	..	..	..	..	3	..	..	..	..	..	..	..	3	7·00
1853	..	..	..	..	..	..	..	..	..	..	..	3	..	..	..	..	..	..	..	..	3	8·00
1854	..	..	..	..	..	..	..	..	..	..	3	..	..	..	..	..	..	..	1	..	4	7·00
1855	..	..	..	..	..	..	..	..	..	3	..	..	..	..	..	..	..	1	1	..	5	6·60
1856	..	..	..	..	..	..	..	..	3	..	..	..	..	..	..	..	1	1	..	..	5	7·60
1857	..	..	..	..	..	..	..	3	..	..	..	..	..	..	..	1	1	..	..	..	5	8·60
1858	..	..	..	..	..	..	3	..	..	..	..	..	..	..	1	1	..	..	..	..	5	9·60
1859	..	..	..	..	..	3	..	..	..	..	..	..	..	1	1	..	..	..	..	..	5	10·60
1860	..	..	..	..	3	..	..	..	..	..	..	..	1	1	..	..	..	..	..	..	5	11·60
1861	..	..	..	3	..	..	..	..	..	..	..	1	1	..	..	..	..	..	..	..	5	12·60
1862	..	..	3	..	..	..	..	..	..	..	1	1	..	..	..	..	..	..	..	..	5	13·60
June, 1863	..	3	..	..	..	..	..	..	..	1	1	..	..	..	..	..	..	..	..	..	5	14·60
Dec., 1863	..	3	..	..	..	..	..	..	..	1	1	..	..	..	..	..	..	..	..	..	5	14·60
June, 1864	3	..	..	..	..	..	..	..	1	1	..	..	..	..	..	..	..	..	..	..	5	15·60
Dec., 1864	3	..	..	..	..	..	..	..	1	1	..	..	..	..	..	..	..	..	..	..	5	15·60

NORTH EASTERN RAILWAY.

Ages of Goods Wagons.

DATES.	YEARS.																									Total Rebuilt in the Half-Year.	Total Number of Stock.	Average Age in Years.
	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
1852	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	77	60	50	46	80	338	..	300	208	100	..	..	..	1,259	6·46
1853	..	..	..	..	..	..	..	..	..	..	..	..	..	..	125	210	266	271	207	550	50	300	159	175	195	26	45	..	2,579	7·89
1854	..	..	..	..	..	..	..	..	..	..	..	..	..	125	210	266	271	207	550	50	300	150	175	195	26	45	398	..	2,977	7·84
1855	..	..	..	..	..	..	..	..	..	..	..	..	124	210	266	271	207	550	50	300	159	175	195	26	45	398	35	1	3,012	8·74
1856	..	..	..	..	..	..	..	..	..	..	..	124	210	266	271	207	550	50	300	159	175	195	26	45	398	36	4	..	3,016	9·73
1857	..	..	..	..	..	..	..	..	..	..	47	100	140	160	150	238	100	148	159	175	158	26	45	292	36	4	331	12	2,321	8·64
1858	..	..	..	..	..	..	..	..	..	14	100	110	160	150	238	100	148	159	175	158	26	45	292	36	4	343	178	33	2,499	8·80
1859	..	..	..	..	..	..	..	..	..	53	140	160	150	238	100	148	159	175	158	26	45	292	36	4	343	211	..	61	2,499	9·38
1860	..	..	..	..	..	..	..	..	..	80	160	150	238	100	148	159	175	158	26	45	292	36	4	343	211	61	321	113	2,820	8·61
1861	..	..	..	..	..	..	..	..	54	160	150	238	100	148	159	175	158	26	45	292	36	4	343	211	61	434	400	26	3,220	8·09
1862	..	..	188	..	..	..	..	34	160	150	238	100	148	159	175	158	26	63	309	110	30	360	217	71	460	429	..	21	3,606	9·97
June, 1863	..	188	..	..	..	..	..	102	150	238	100	148	159	175	158	26	63	309	110	30	360	217	71	460	429	21	4	92	3,610	10·46
Dec., 1863	..	176	..	..	..	..	..	48	150	230	90	133	159	172	158	21	61	309	109	30	360	217	71	460	429	21	201	110	3,715	9·66
June, 1864	145	..	..	..	..	..	..	139	220	54	123	159	172	158	18	61	308	109	30	359	217	71	460	429	21	311	398	151	4,113	9·00
Dec., 1864	129	..	..	..	..	..	..	139	220	54	123	159	172	158	18	61	308	109	30	359	217	71	460	429	21	311	758	16	4,322	8·52

Remarks.—Up to June, 1863, only those Wagons are included in the Column as having been *rebuilt*, which have been entirely new.
The difference in the number of Wagons between 1856 and 1857 is caused by all the Stock at that period having been classed afresh, re-numbered, and marked "N.E."
In 1862 the Stocks of the Hull and Holderness, and Newcastle and Carlisle Railways are included.

NORTH EASTERN RAILWAY.

Ages of Covered Goods Wagons.

DATES.	YEARS.																									Total Rebuilt in the Half-Year.	Total Number of Stock.	Average Age in Years.
	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
1852	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	50	150	48	..	..	..	..	..	248	6·00
1853	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	.	50	300	48	100	75	80	74	112	..	839	4·87
1854	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	50	300	48	100	75	80	74	112	..	..	839	5·87
1855	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	50	300	48	100	75	80	74	112	..	..	..	839	6·87
1856	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	50	300	48	100	75	80	74	112	..	..	..	..	839	7·87
1857	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	47	300	48	100	75	80	74	112	..	..	..	..	3	839	8·83
1858	..	..	..	..	..	..	..	..	..	..	..	..	..	..	46	300	48	100	75	80	74	112	..	..	..	3	..	1	839	9·81
1859	..	..	..	..	..	..	..	..	..	..	..	..	..	45	300	48	100	75	80	74	112	..	..	..	3	1	..	1	839	10·80
1860	..	..	..	..	..	..	..	..	..	..	..	..	27	300	48	100	75	80	74	112	..	..	..	3	1	1	..	18	839	11·50
1861	..	..	..	..	..	..	..	..	..	..	..	24	300	48	100	75	80	74	112	..	..	..	3	1	1	18	..	3	839	12·44
1862	..	..	80	..	..	..	..	..	..	..	22	300	48	100	75	80	74	114	..	..	..	4	1	2	18	14	1	9	942	14·14
June, 1863	..	80	..	..	..	..	..	..	..	22	300	48	100	75	80	74	114	..	..	..	4	1	2	18	14	10	..	..	942	15·13
Dec., 1863	..	80	..	..	..	..	..	..	..	20	300	48	100	75	80	74	113	..	..	..	4	1	2	18	14	10	..	3	942	15·08
June, 1864	80	..	..	..	..	..	..	..	20	300	48	100	75	80	74	113	..	..	..	4	1	2	18	14	10	3	..	..	942	16·08
Dec., 1864	70	..	..	..	..	..	..	..	20	284	48	100	75	80	74	113	..	..	..	4	1	2	18	14	10	3	..	26	942	15·52

Remarks.—Up to June, 1863, only those Wagons are included in the Column as having been *rebuilt* which have been entirely new. In 1862 the Stocks of the Hull and Holderness, and Newcastle and Carlisle Railways are included.

NORTH EASTERN RAILWAY.

Ages of Sheep and Box Wagons.

DATES.	YEARS.																		Total Rebuilt in the Half-Year.	Total Number of Stock.	Average Age in Years.
	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
1852	..	..	..	..	..	..	..	..	..	..	..	..	146	..	..	..	..	..	..	146	6·00
1853	..	..	..	..	..	..	..	..	..	..	..	146	..	..	..	..	..	..	..	146	7·00
1854	..	..	..	..	..	..	..	..	..	..	146	..	..	..	..	..	..	..	..	146	8·00
1855	..	..	..	..	..	..	..	..	..	146	..	..	..	..	..	..	..	..	..	146	9·00
1856	..	..	..	..	..	..	..	..	146	..	..	..	..	..	..	..	..	..	..	146	10·00
1857	..	..	..	..	..	..	..	485	..	..	..	..	..	..	..	..	..	..	..	485	11·00
1858	..	..	..	..	..	..	485	..	..	..	..	..	..	..	..	..	..	..	..	485	12·00
1859	..	..	..	..	..	481	..	..	..	..	..	..	..	..	..	..	..	..	4	485	12·90
1860	..	..	..	..	481	..	..	..	..	..	..	..	..	..	..	..	4	..	..	485	13·90
1861	..	..	..	448	..	..	..	..	..	..	..	..	..	..	..	4	..	..	33	485	13·94
1862	..	..	448	..	..	..	..	..	..	..	..	..	..	..	4	..	33	..	..	485	14·94
June, 1863	..	448	..	..	..	..	..	..	..	..	..	..	..	4	..	33	..	..	..	485	15·94
Dec., 1863	..	448	..	..	..	..	..	..	..	..	..	..	..	4	..	33	..	..	..	485	15·94
June, 1864	448	..	..	..	..	..	..	..	..	..	..	..	4	..	33	..	..	..	..	485	16·94
Dec., 1864	448	..	..	..	..	..	..	..	..	..	..	..	4	..	33	..	..	..	..	485	16·94

Remarks.—Up to June, 1863. only those Wagons are included in the Column as having been *rebuilt* which have been entirely new.
The difference in the number of Wagons between 1856 and 1857 is caused by all the Stock at that period having been classed afresh, re-numbered, and marked "N. E."

NORTH EASTERN RAILWAY.

Ages of Cattle Wagons.

DATES.	YEARS.																									Total Rebuilt in the Half-Year.	Total Number of Stock.	Average Age in Years.
	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
1852	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	50	63	20	121	..	..	..	..	..	254	6·16
1853	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	25	100	85	55	146	..	..	..	50	..	..	461	6·92
1854	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	24	100	85	55	146	..	..	..	50	..	60	1	521	7·10
1855	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	23	100	85	55	146	..	..	..	50	..	61	..	1	521	8·08
1856	..	..	..	..	..	..	..	..	..	..	..	..	..	..	23	100	85	55	146	..	..	..	50	..	61	1	..	..	521	9·08
1857	..	..	..	..	..	..	..	..	..	..	..	..	..	22	100	85	55	146	..	..	..	50	..	61	1	..	76	1	597	8·92
1858	..	..	..	..	..	..	..	..	..	..	..	..	17	100	85	55	146	..	..	..	50	..	61	1	..	77	..	5	597	9·78
1859	..	..	..	..	..	..	..	..	..	..	..	..	89	85	55	146	..	..	..	50	..	61	1	..	77	5	..	28	597	10·10
1860	..	..	..	..	..	..	..	..	..	..	..	67	85	55	146	..	..	..	50	..	61	1	..	77	5	28	..	22	597	10·55
1861	..	..	..	..	..	..	..	..	..	..	51	85	55	146	..	..	..	50	..	61	1	..	77	5	28	22	..	16	597	11·12
1862	..	..	54	..	..	..	..	..	..	..	..	20	146	..	..	..	51	..	61	1	4	84	6	31	23	20	..	173	674	8·67
June, 1863	..	47	..	..	..	..	..	..	..	..	20	146	..	..	..	51	..	61	1	4	84	6	31	23	20	173	..	7	674	9·54
Dec., 1863	..	44	..	..	..	..	..	..	..	..	..	71	..	..	..	49	..	61	1	4	84	6	31	23	20	173	7	100	674	7·27
June, 1864	42	..	..	..	..	..	..	..	..	..	66	..	..	..	46	..	61	1	4	84	6	31	23	19	173	107	..	11	674	8·02
Dec., 1864	20	..	..	..	..	..	..	..	..	..	66	..	..	..	46	..	61	1	4	84	6	31	23	19	173	107	11	22	674	7·17

Remarks.—Up to June, 1863, only those Wagons are included in the Column as having been *rebuilt* which have been entirely new.
In 1862 the Stocks of the Hull and Holderness, and Newcastle and Carlisle Railways are included.

NORTH EASTERN RAILWAY.

Ages of Timber Wagons.

DATES.	YEARS.																			Total Rebuilt in the Half-Year.	Total Number of Stock.	Average Age in Years.
	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
1852	..	..	..	..	..	..	..	..	..	..	..	..	30	50	22	40	..	..	..	..	142	5·57
1853	..	..	..	..	..	..	..	..	..	..	..	43	60	72	251	..	..	..	..	..	426	5·75
1854	..	..	..	..	..	..	..	..	..	..	43	60	72	251	..	..	..	..	300	..	726	4·37
1855	..	..	..	..	..	..	..	..	..	43	60	72	251	..	..	..	..	300	..	..	726	5·37
1856	..	..	..	..	..	..	..	..	43	60	72	251	..	..	..	..	300	..	2	..	728	6·36
1857	..	..	..	..	..	..	..	139	260	172	287	..	..	..	..	300	..	2	198	4	1,362	7·51
1858	..	..	..	..	..	..	134	260	172	287	..	..	..	..	300	..	2	202	..	5	1,362	8·47
1859	..	..	..	..	..	131	260	172	287	..	..	..	..	300	..	2	202	5	..	3	1,362	9·37
1860	..	..	..	..	123	260	172	287	..	..	..	..	300	..	2	202	5	3	200	8	1,562	9·16
1861	..	..	..	123	260	172	287	..	..	..	..	300	..	2	202	5	3	208	200	..	1,762	9·12
1862	..	..	121	260	172	287	..	..	..	..	300	..	2	202	5	3	208	200	..	2	1,762	10·10
June, 1863	..	121	260	172	287	..	..	..	..	300	..	2	202	5	3	208	200	2	..	..	1,762	11·10
Dec., 1863	..	115	260	172	286	..	..	..	..	299	..	2	202	5	3	208	200	2	104	8	1,866	10·47
June, 1864	115	260	172	286	..	..	..	..	299	..	2	202	5	3	208	200	2	112	..	..	1,866	11·47
Dec., 1864	115	260	171	286	..	..	..	..	299	..	2	202	5	3	208	200	2	112	30	1	1,896	11·30

Remarks.—Up to June, 1863, only those Wagons are included in the Column as having been *rebuilt* which have been entirely new. The difference in the number of Wagons between 1856 and 1857 is caused by all the Stock at that period having been classed afresh, renumbered, and marked "N. E."

NORTH EASTERN RAILWAY.

Ages of Six-Ton Coal Wagons.

Dates.	Years.																			Total Rebuilt in the Half-Year.	Total Number of Stock.	Average Age in Years.
	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
1852	..	..	..	..	..	..	..	..	..	..	..	..	569	41	432	200	..	..	..	..	1,242	5·78
1853	..	..	..	..	..	..	..	..	..	..	..	869	561	743	404	..	97	35	34	..	2,743	6·47
1854	..	..	..	..	..	..	..	..	..	..	869	561	743	404	..	97	35	34	..	..	2,743	7·47
1855	..	..	..	..	..	..	..	..	..	869	561	743	404	...	97	35	34	..	..	..	2,743	8·47
1856	..	..	..	..	..	..	..	..	869	561	743	404	..	97	35	34	..	..	..	..	2,743	9·47
1857	..	..	..	..	..	..	..	568	461	643	332	..	97	35	34	..	..	..	..	1	2,171	10·30
1858	..	..	..	..	..	..	565	461	643	332	..	97	35	34	..	..	..	1	..	3	2,171	11·28
1859	..	..	..	..	..	553	461	643	332	..	97	35	34	..	..	..	1	3	..	12	2,171	12·21
1860	..	..	..	..	547	461	643	332	..	97	35	34	..	..	..	1	3	12	..	6	2,171	13·17
1861	..	..	..	544	461	643	332	..	97	35	34	..	..	..	1	3	12	6	147	3	2·318	13·31
1862	..	..	532	498	678	332	..	97	35	34	..	..	..	1	3	17	30	248	52	13	2,570	13·37
June, 1863	..	532	498	678	332	..	97	35	34	..	..	..	1	3	17	30	248	65	..	..	2,570	14·37
Dec., 1863	..	508	495	678	331	..	97	35	34	..	..	..	1	3	17	30	248	65	..	28	2,570	14·22
June, 1864	507	489	678	331	..	96	34	33	..	..	..	1	3	17	30	248	65	28	..	10	2,570	15·16
Dec., 1864	400	484	675	331	..	96	34	33	..	..	..	1	3	17	30	248	65	28	10	115	2,570	14·36

Remarks.—Up to June, 1863, only those Wagons are included in the Column as having been *rebuilt* which have been entirely new. The difference in the number of the several descriptions of Wagons between 1856 and 1857 is caused by all the Stock at that period having been classed afresh, re-numbered, and marked "N. E."
In 1862 the Stocks of the Hull and Holderness, and Newcastle and Carlisle Railways are included.

NORTH EASTERN RAILWAY.

Ages of Eight-ton Coal Wagons.

DATES.	YEARS.											Total Rebuilt in the Half-Year.	Total Number of Stock.	Average Age in Years.
	11	10	9	8	7	6	5	4	3	2	1			
1854	..	..	..	..	..	..	..	..	..	..	33	..	33	1·00
1855	..	..	..	..	..	..	..	..	..	33	448	..	481	1·06
1856	..	..	..	..	..	..	..	..	33	448	3	..	484	2·06
1857	..	..	..	..	..	..	..	33	448	3	200	..	684	2·45
1858	..	..	..	..	..	..	32	448	3	200	33	1	717	3·34
1859	..	..	..	..	..	31	448	3	200	34	150	1	867	3·75
1860	..	..	..	..	31	448	3	200	34	151	417	..	1,284	3·32
1861	..	..	..	31	448	3	200	34	151	417	842	..	2,126	3·13
1862	..	..	31	448	3	200	34	151	417	842	..	..	2,126	4·13
June, 1863	..	31	448	3	200	34	151	417	842	..	..	..	2,126	5·13
Dec., 1863	..	31	443	3	200	34	151	417	841	..	..	6	2,126	5·11
June, 1864	31	443	3	200	34	151	417	841	..	6	..	..	2,126	6·11
Dec., 1864	31	443	3	200	34	151	417	841	..	6	100	..	2,226	5·88

Remarks.—Up to June, 1863, only those Wagons are included in the Column as having been *rebuilt* which have been entirely new.

NORTH EASTERN RAILWAY.

Ages of Coke and Lime Wagons.

DATES.	YEARS.																									Total Rebuilt in the Half-Year.	Total Number of Stock.	Average Age in Years.
	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
1852	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	69	256	207	244	..	..	..	..	776	5·19
1853	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	383	302	207	241	..	..	..	..	..	1,136	6·72
1854	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	383	302	207	244	..	..	..	..	..	..	1,136	7·72
1855	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	383	302	207	244	..	..	..	..	..	..	..	1,136	8·72
1856	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	383	302	207	244	..	..	..	..	..	..	..	..	1,136	9·72
1857	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	574	501	257	244	..	..	..	..	..	..	..	..	181	9	1,766	9·82
1858	..	..	..	..	..	..	..	..	..	..	..	..	..	..	559	501	257	244	..	..	..	..	..	..	..	..	190	23	15	1,789	10·49
1859	..	..	..	..	..	..	..	..	..	..	..	..	..	513	501	257	244	..	..	..	..	..	..	..	..	190	38	..	46	1,789	11·26
1860	..	..	..	..	..	..	..	..	..	..	..	..	483	501	257	244	..	..	..	..	..	..	..	..	190	38	46	..	30	1,789	12·03
1861	..	..	..	..	..	..	..	..	..	..	..	473	501	257	244	..	..	..	..	..	..	..	190	38	46	30	116	10	1,905	12·21
1862	..	..	140	..	..	..	..	..	..	..	438	501	257	244	..	..	..	..	..	..	1	210	39	50	45	128	129	38	2,220	12·81
June, 1863	..	140	..	..	..	..	..	..	..	379	501	257	244	..	..	..	..	..	..	1	210	39	50	45	128	167	..	59	2,220	13·36
Dec., 1863	..	140	..	..	..	..	..	..	..	375	501	257	244	..	..	..	..	..	..	1	210	39	50	45	128	167	73	4	2,234	13·25
June, 1864	137	..	..	..	..	..	..	..	367	498	257	244	..	..	..	..	..	..	1	210	39	50	45	128	167	77	169	14	2,403	13·23
Dec., 1864	110	..	..	..	..	..	..	..	360	495	257	244	..	..	..	..	..	..	1	210	39	50	45	128	167	77	232	37	2,452	12·60

Remarks.—Up to June, 1863, only those Wagons are included in the Column as having been *rebuilt* which have been entirely new.
The difference in the number of Wagons between 1856 and 1857 is caused by all the stock at that period having been classed afresh, re-numbered, and marked "N. E."
In 1862 the Stocks of the Hull and Holderness, and Newcastle and Carlisle Railways are included.

NORTH EASTERN RAILWAY.

Ages of Hopper Iron Wagons.

DATES.	YEARS.									Total Rebuilt in the Half-Year.	Total Number of Stock.	Average Age in Years.
	9	8	7	6	5	4	3	2	1			
1852	..	..	..	.	..	..	..	..	..	..	..	..
1853	..	..	..	..	..	..	..	..	..	..	..	..
1854	..	..	..	..	..	..	..	..	..	..	..	..
1855	..	..	..	..	..	..	..	..	..	..	..	..
1856	..	..	..	..	..	..	..	..	40	..	40	1·00
1857	..	..	..	..	..	..	..	40	262	..	302	1·13
1858	..	..	..	..	..	..	40	262	..	..	302	2·13
1859	..	..	..	..	..	40	262	..	..	..	302	3·13
1860	..	..	..	..	40	262	..	..	61	..	363	3·60
1861	..	..	..	40	262	..	..	61	339	..	702	2·86
1862	..	..	40	262	..	..	61	339	56	..	758	3·65
June, 1863	..	40	262	..	..	61	339	56	236	..	994	3·78
Dec., 1863	..	40	262	..	..	61	339	56	294	..	1,052	3·63
June, 1864	40	262	..	..	61	339	56	294	..	..	1,052	4·63
Dec., 1864	40	262	..	..	61	339	56	294	..	..	1,052	4·63

NORTH EASTERN RAILWAY.

Ages of Ironstone Wagons.

DATES.	YEARS.								Total Rebuilt in the Half-Year.	Total Number of Stock.	Average Age in Years.
	8	7	6	5	4	3	2	1			
1857	..	..	..	..	..	..	..	100	..	100	1·00
1858	..	..	..	..	..	..	100	..	..	100	2·00
1859	..	..	..	..	..	100	..	..	..	100	3·00
1860	..	..	..	..	100	..	..	..	..	100	4·00
1861	..	..	..	98	..	..	..	..	2	100	4·92
1862	..	..	93	..	..	..	2	..	5	100	5·67
June, 1863	..	93	..	..	..	2	5	..	..	100	6·67
Dec., 1863	..	89	..	..	..	2	5	..	4	100	6·43
June, 1864	89	..	..	..	1	5	3	..	2	100	7·39
Dec., 1864	84	..	..	..	1	5	3	2	5	100	7·04

Remarks.—Up to June, 1863, only those Wagons are included in the Column as having been *rebuilt* which have been entirely new.

NORTH EASTERN RAILWAY.

Ages of Ballast Wagons.

DATES.	YEARS.																						Total Rebuilt in the Half-Year.	Total Number of Stock.	Average Age in Years.
	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
1852	..	..	..	..	..	..	..	..	..	..	..	40	36	..	..	..	..	..	..	..	..	..	..	..	76	11·52
1853	..	..	..	..	..	..	..	..	..	..	40	36	29	..	..	..	..	..	..	..	..	..	..	..	105	12·10
1854	..	..	..	..	..	..	..	..	..	40	36	29	..	..	..	..	..	..	..	..	..	..	..	..	105	13·10
1855	..	..	..	..	..	..	..	..	40	36	29	..	..	..	..	..	..	..	..	..	..	..	..	..	105	14·10
1856	..	..	..	..	..	..	..	40	36	29	..	..	..	..	..	..	..	..	..	..	..	..	..	..	105	15·10
1857	..	..	..	..	..	..	30	36	29	..	..	..	..	..	..	..	131	100	..	..	..	..	..	..	10	336	9·07
1858	..	..	..	..	..	15	36	29	..	..	..	..	..	..	..	131	100	..	..	..	..	10	..	15	336	9·31
1859	..	..	..	..	12	36	29	..	..	..	..	..	..	..	131	100	..	..	..	..	10	15	..	3	336	10·15
1860	..	..	..	9	36	29	..	..	..	..	..	..	..	131	100	..	..	..	..	10	15	3	..	3	336	10·98
1861	..	..	..	30	29	..	..	..	..	..	..	..	131	100	..	..	..	..	10	15	3	3	24	15	360	10·43
1862	..	..	30	29	..	..	..	..	..	..	..	131	100	..	20	10	..	10	15	3	3	39	..	..	390	11·22
June, 1863	..	30	29	..	..	..	..	..	..	..	131	100	..	29	10	..	10	15	3	3	39	..	20	..	410	11·67
Dec., 1863	..	30	29	..	..	..	..	..	..	..	131	100	..	19	9	..	10	15	3	3	39	..	24	2	414	11·52
June, 1864	30	29	..	..	..	..	..	..	..	131	100	..	19	9	..	10	14	3	3	39	..	26	..	1	414	12·52
Dec., 1864	29	29	..	..	..	..	..	..	..	131	100	..	19	9	..	10	14	3	3	39	..	26	8	1	421	12·27

Remarks.—Up to June, 1863, only those Wagons are included in the Column as having been *rebuilt* which have been entirely new.

The difference in the number of Wagons between 1856 and 1857 is caused by all the Stock at that period having been classed afresh, re-numbered, and marked "N. E."

In 1862 the Stocks of the Hull and Holderness, and Newcastle and Carlisle Railways are included.

NORTH EASTERN RAILWAY.

Ages of Water and Creosote Tanks.

DATES.	YEARS.													Total Rebuilt in the Half-Year.	Total Number of Stock.	Average Age in Years.
	13	12	11	10	9	8	7	6	5	4	3	2	1			
1852	..	..	..	..	..	..	..	..	..	..	..	..	8	..	8	1·00
1853	..	..	..	..	..	..	..	..	..	..	..	8	..	..	8	2·00
1854	..	..	..	..	..	..	..	..	..	..	16	..	..	..	16	3·00
1855	..	..	..	..	..	..	..	..	..	23	..	..	..	..	23	4·00
1856	..	..	..	..	..	..	..	..	23	..	..	..	..	..	23	5·00
1857	..	..	..	..	..	..	..	23	..	..	..	..	..	..	23	6·00
1858	..	..	..	..	..	..	23	..	..	..	..	..	..	..	23	7·00
1859	..	..	..	..	..	23	..	..	..	..	..	..	..	..	23	8·00
1860	..	..	..	..	23	..	..	..	..	..	..	..	..	..	23	9·00
1861	..	..	..	23	..	..	..	..	..	..	..	..	..	..	23	10·00
1862	..	..	22	..	..	..	..	..	..	..	..	..	..	1	23	10·56
June, 1863	..	22	..	..	..	..	..	..	..	..	..	1	..	..	23	11·56
Dec., 1863	..	22	..	..	..	..	..	..	..	..	..	1	..	..	23	11·56
June, 1864	22	..	..	..	..	..	..	..	..	..	1	..	..	..	23	12·56
Dec., 1864	22	..	..	..	..	..	..	..	..	..	1	..	..	..	23	12·56

Remarks.—Up to June, 1863, only those Wagons are included in the Column as having been *rebuilt* which have been entirely new.

NORTH EASTERN RAILWAY.

Ages of Stone Wagons.

DATES.	YEARS.																										Total Rebuilt in the Half-Year.	Total Number of Stock.	Average Age in Years.
	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
1852	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	36	..	..	..	..	..	36	5·00
1853	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	36	..	..	..	..	..	..	36	6·00
1854	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	36	..	..	..	..	..	..	..	36	7·00
1855	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	36	..	..	..	..	..	..	..	..	36	8·00
1856	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	36	..	..	..	..	..	..	..	..	..	36	9·00
1857	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	36	..	..	..	..	..	..	..	..	..	..	36	10·00
1858	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	36	..	..	..	..	..	..	..	..	..	..	..	36	11·00
1859	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	36	..	..	..	..	..	..	..	..	..	..	..	..	36	12·00
1860	..	..	..	..	..	..	..	..	..	..	..	..	..	..	36	..	..	..	..	..	..	..	..	..	..	..	..	..	36	13·00
1861	..	..	..	..	..	..	..	..	..	..	..	..	..	36	..	..	..	..	..	..	..	..	..	..	..	..	..	..	36	14·00
1862	..	..	17	..	..	..	..	..	..	..	..	..	36	..	..	..	13	9	31	5	..	7	..	1	..	2	..	..	121	12·95
June, 1863	..	17	..	..	..	..	..	..	..	..	..	36	..	..	..	13	9	31	5	..	7	..	1	..	2	..	..	..	121	13·95
Dec., 1863	..	17	..	..	..	..	..	..	..	..	..	36	..	..	..	13	9	31	5	..	7	..	1	..	2	..	..	..	121	13·95
June, 1864	17	..	..	..	..	..	..	..	..	..	36	..	..	..	13	9	31	5	..	7	..	1	..	2	..	..	..	..	121	14·95
Dec.. 1864	..	..	..	..	..	..	..	..	..	..	21	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	*21	17·00

Remarks.—In 1862 the Stocks of the Hull and Holderness, and Newcastle and Carlisle Railways are included.
* 100 Stone Wagons broken up and rebuilt as "Goods" Wagons. As per Board Min. Oct. 23rd, 1863.

NORTH EASTERN RAILWAY.

Ages of Locomotive Engines.

DATES.	YEARS.																									Total Rebuilt in the Half-Year.	Total Number of Stock.	Average Age in Years.
	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
1852	..	..	..	..	..	..	..	..	..	..	..	1	..	5	35	4	3	3	..	5	22	10	46	22	13	11	10	9	209	6·81
1853	..	..	..	..	..	..	..	..	..	..	..	..	3	35	31	10	5	2	5	31	31	70	47	33	16	19	10	3	351	7·20
1854	..	..	..	..	..	..	..	..	..	..	..	2	33	30	8	4	2	5	31	30	70	47	33	16	19	13	33	8	384	7·33
1855	..	..	..	..	..	..	..	..	..	..	1	31	28	8	4	2	5	30	28	70	47	31	14	19	13	41	16	12	400	7·74
1856	..	..	..	..	..	..	..	..	..	1	29	28	8	4	2	5	30	27	70	47	31	14	19	13	14	28	4	3	404	8·56
1857	..	..	..	..	..	..	..	..	..	28	27	7	4	2	5	29	25	70	47	31	14	19	13	41	28	7	10	7	414	9·12
1858	..	..	..	..	..	..	..	..	26	26	6	4	2	5	29	25	69	47	31	14	19	13	41	28	7	17	..	5	414	9·93
1859	..	..	..	..	..	..	..	25	24	6	3	2	5	28	23	68	46	31	14	19	13	41	28	7	17	5	..	9	414	10·62
1860	..	..	..	..	..	..	19	24	5	3	2	5	28	23	67	46	31	14	19	13	41	28	7	17	5	9	6	8	420	11·11
1861	..	..	..	..	..	13	24	3	3	2	5	28	23	66	46	31	14	19	13	41	28	7	17	5	9	14	26	9	446	11·07
1862	..	1	1	3	16	25	5	3	2	4	27	23	62	45	33	14	20	13	44	29	11	17	5	12	15	38	..	19	487	11·64
June, 1863	1	1	3	16	25	5	3	2	4	27	22	61	42	33	14	20	13	44	29	11	17	5	12	15	38	19	4	5	491	12·43
Dec., 1863	1	1	3	16	25	5	2	2	4	25	21	61	42	32	14	20	13	44	29	11	17	5	12	15	38	19	9	5	491	12·23
June, 1864	..	1	16	25	5	2	2	4	25	21	61	42	32	14	20	13	44	29	11	17	5	12	15	38	19	14	..	4	491	13·02
Dec., 1864	..	..	15	25	5	2	2	4	24	20	60	41	32	14	20	13	44	29	11	17	5	12	15	38	19	14	17	6	504	12·48

Remarks.—Up to June, 1863, only those Engines are included in the Column as having been *rebuilt* which have been entirely new, and of a different class in rebuilding. When an Engine has had a new Boiler, and otherwise new, it has not been included as being rebuilt, though entirely new, if rebuilt of the same class.

In 1862 the Stocks of the Hull and Holderness, and Newcastle and Carlisle Railways are included.

NORTH EASTERN RAILWAY.

STATEMENT showing the NUMBER, AVERAGE AGE, COST, &c., of the LOCOMOTIVE ENGINE STOCK at the undermentioned Periods.

DATES.	Total Locomotive Stock.		Total Cost.	Cost of Repairs and Upholding.	Per Centage of Repairs on Total Cost.	Miles Run by Locomotive Engines.	Cost per Mile for Repairs and Upholding.	Extraordinary Repairs, included under "Repairs and Upholding."
	No.	Average Age.						
		Years.	£. s. d.	£. s. d.	£.		d.	£. s. d.
1852	209	6·81	405,773 14 11	51,395 12 1	12·66	3,688,776	3·34	35,939 13 9
1853	351	7·20	684,787 16 3	87,990 16 0	12·84	7,311,369	2·88	57,829 1 7
1854	384	7·33	768,687 16 3	113,591 18 5	14·77	7,970,520	3·42	71,853 19 0
1855	400	7·75	810,287 16 3	108,319 19 6	13·37	7,840,275	3·31	68,902 3 1
1856	404	8·56	820,687 16 3	92,098 1 3	11·22	7,734,664	2·85	59,122 8 2
1857	414	9·12	846,687 16 3	104,974 15 5	12·40	8,299,088	3·03	69,562 7 11
1858	414	9·93	846,687 16 3	98,810 11 10	11·67	8,150,643	2·91	63,099 16 6
1859	414	10·62	846,687 16 3	106,901 17 3	12·62	8,261,084	3·10	69,139 13 1
1860	420	11·11	858,170 0 0	110,415 12 6	12·86	8,937,632	2·96	73,292 6 10
1861	446	11·07	928,050 0 0	116,166 0 4	12·51	9,642,387	2·89	76,868 0 7
1862	487	11·64	1,001,250 0 0	117,944 16 11	11·77	10,118,172	2·79	78,134 4 9
June, 1863	491	12·43	1,012,050 0 0	63,095 10 8	6·23	5,265,731	2·87	42,491 4 2
Dec., 1863	491	12·23	1,012,050 0 0	61,148 15 2	6·04	5,705,725	2·57	38,224 1 9
June, 1864	491	13·02	1,012,050 0 0	64,156 11 0	6·34	5,685,812	2·71	39,022 2 11
Dec., 1864	504	12·48	1,047,770 0 0	68,586 16 3	6·54	6,248,493	2·63	42,530 5 6

NORTH EASTERN RAILWAY.

STATEMENT showing the NUMBER, DESCRIPTION, and AVERAGE AGE of the CARRIAGE STOCK at the undermentioned Periods.

DATES.	DESCRIPTIONS OF CARRIAGE STOCK.														Total Carriage Stock.	
	First-Class Carriages.		Composite Carriages.		Second-Class Carriages.		Third-Class Carriages.		Luggage and Parcels Vans.		Horse Boxes.		Carriage Trucks.			
	No.	Average Age.	No.	Average Age.	No.	Average Age.	No.	Average Age.	No.	Average Age.	No.	Average Age.	No.	Average Age.	No.	Average Age.
		Years.		Years.		Years.		Years.		Years.		Years.		Years.		Years.
1852	89	7·28	33	10·00	130	7·17	79	8·96	26	5·46	35	8·65	28	8·92	420	8·15
1853	170	7·73	72	9·25	213	8·91	189	4·58	105	7·20	79	8·39	52	10·30	880	7·61
1854	176	8·40	79	9·43	213	9·30	239	6·22	133	6·68	79	8·33	52	11·10	971	8·05
1855	196	8·55	79	9·89	213	9·77	239	6·32	145	6·86	79	9·32	52	11·50	1,003	8·33
1856	196	9·15	79	9·37	213	10·07	239	6·81	145	7·40	79	9·93	52	12·04	1.003	9·06
1857	196	9·76	79	9·97	213	10·60	239	6·81	145	8·35	79	10·73	52	10·92	1,003	9·15
1858	196	10·25	79	9·96	213	10·92	279	6·77	145	8·99	99	9·11	52	11·18	1,063	9·20
1859	196	10·55	79	9·52	213	11·32	279	7·71	155	8·87	99	9·35	52	11·88	1,073	9·56
1860	196	10·53	79	8·96	213	10·92	279	8·66	155	8·89	99	9·77	52	12·88	1,073	9·79
1861	200	10·87	85	7·49	214	10·96	304	8·68	169	8·99	99	10·77	52	13·88	1,123	9.83
1862	217	11·38	93	9·22	238	11·97	383	9·61	188	7·93	112	12·01	61	10·93	1,292	10·25
June, 1863	218	11·22	105	9·17	238	12·14	383	10·50	188	8·16	112	11·47	61	10·21	1,305	10·54
Dec., 1863	218	10·77	105	9·17	238	11·20	383	10·12	188	7·72	112	10·83	61	10·21	1,305	10·07
June, 1864	218	11·33	114	9·44	250	10·25	383	11·05	198	7·90	112	11·51	61	10·78	1,336	10·37
Dec., 1864	218	10·98	129	8·16	250	9·69	395	10·29	205	7·27	112	11·51	61	10·78	1,370	9·75

REMARKS.—Up to June, 1863, only those Carriages are included in the Column as having been *rebuilt* which have been entirely new.
In 1862 the Stocks of the Hull and Holderness, and Newcastle and Carlisle Railways are included.

NORTH EASTERN RAILWAY.

STATEMENT showing the TOTAL COST of CARRIAGE STOCK, COST of REPAIRS, COST per VEHICLE, per Annum, for Repairing and Upholding, at the undermentioned Periods.

DATES.	Total Cost of Carriage Stock.	Total Cost of Repairing and Rebuilding.	Per Centage of Repairs and Rebuilding on Total Cost.	Cost of Repairing and Rebuilding per Carriage per Annum.	Cost of Rebuilding.
	£. s. d.	£. s. d.	£.	£. s. d.	£. s. d.
1852	78,367 14 2	7,459 14 11	9·51	17 15 4	.. ..
1853	160,554 2 6	14,029 17 9	8·73	15 18 10	.. ..
1854	176,974 2 6	17,734 1 1	10·02	18 5 3	.. ..
1855	191,579 12 8	20,344 4 8	10·61	20 5 8	.. ..
1856	191,579 12 8	20,016 16 4	10·44	19 19 1	.. ..
1857	191,579 12 8	20,455 18 8	10·67	20 7 10	.. ..
1858	207,413 12 8	21,242 17 2	10·21	19 19 8	6,822 0 0
1859	209,163 12 8	25,200 15 9	12·04	23 9 8	9,079 0 0
1860	209,163 12 8	29,375 3 4	14·04	27 7 6	12,041 0 0
1861	220,644 4 7	28,369 7 7	12·85	25 5 2	8,198 0 0
1862	266,129 4 7	33,193 5 11	12·47	25 13 9	10,350 0 0
June, 1863	269,919 4 7	16,361 3 4	6·06	12 10 8	6,870 0 0
Dec., 1863	269,919 4 7	16,733 10 7	6·19	12 16 5	7,740 0 0
June, 1864	277,089 4 7	15,412 11 5	5·56	11 10 9	7,028 0 0
Dec., 1864	284,835 4 7	13,373 14 7	4·69	9 15 2	6,398 0 0

NORTH EASTERN RAILWAY.

STATEMENT showing the NUMBER, DESCRIPTION, and AVERAGE AGE of the WAGON STOCK, at the undermentioned Periods.

DATES.	DESCRIPTIONS OF WAGON STOCK.															
	Goods Brake Vans.		Stores Vans.		Goods Wagons.		Covered Goods Wagons.		Sheep or Box Wagons.		Cattle Wagons.		Timber Wagons.		Large Coal Wagons.	
	No.	Average Age.	No.	Average Age.	No.	Average Age.	No.	Average Age.	No.	Average Age.	No.	Average Age.	No.	Average Age.	No.	Average Age.
		Years.		Years.		Years.		Years.		Years.		Years.		Years.		Years.
1852	20	9·20	3	7·00	1,259	6·46	248	6·00	146	6·00	254	6·16	142	5·57	1,242	5·78
1853	62	5·58	3	8·00	2,579	7·89	839	4·87	146	7·00	461	6·92	426	5·75	2,743	6·47
1854	98	4·53	4	7·00	2,977	7·84	839	5·87	146	8·00	521	7·10	726	4·37	2,743	7·47
1855	98	5·53	5	6·60	3,012	8·74	839	6·87	146	9·00	521	8·08	726	5·37	2,743	8·47
1856	98	6·53	5	7·60	3,016	9·73	839	7·87	146	10·00	521	9·08	728	6·36	2,743	9·47
1857	104	7·01	5	8·60	2,321	8·64	839	8·83	485	11·00	597	8·92	1,362	7·51	2,171	10·30
1858	104	8·01	5	9·60	2,499	8·80	839	9·81	485	12·00	597	9·78	1,362	8·47	2,171	11·28
1859	106	9·03	5	10·60	2,499	9·38	839	10·80	485	12·90	597	10·10	1,362	9·37	2,171	12·21
1860	110	9·23	5	11·60	2,820	8·61	839	11·50	485	13·90	597	10·55	1,562	9·16	2,171	13·17
1861	142	8·02	5	12·60	3,220	8·09	839	12·44	485	13·94	597	11·12	1,762	9.12	2,318	13·31
1862	179	6·25	5	13·60	3,606	9·97	942	14·14	485	14·94	674	8·67	1,762	10·10	2,570	13·37
June, 1863	185	6·73	5	14·60	3,610	10·46	942	15·13	485	15·94	674	9·54	1,762	11·10	2,570	14·37
Dec., 1863	186	6·42	5	14·60	3,715	9·66	942	15·08	485	15·94	674	7·27	1,866	10·47	2,570	14·22
June, 1864	207	6·71	5	15·60	4,113	9·00	942	16·08	485	16·94	674	8·02	1,866	11·47	2,570	15·16
Dec., 1864	240	5·65	5	15·60	4,322	8·52	942	15·52	485	16·94	674	7·17	1,896	11·30	2,570	14·36

(Continued on page 488.)

(Continued from page 487.)

NORTH EASTERN RAILWAY.

STATEMENT showing the NUMBER, DESCRIPTION, and AVERAGE AGE of the WAGON STOCK, at the undermentioned Periods—*continued.*

DESCRIPTIONS OF WAGON STOCK.														TOTAL WAGON STOCK.		DATES.
Eight Ton Coal Wagons.		Coke and Lime Wagons.		Hopper Iron Wagons.		Ironstone Wagons.		Ballast Wagons.		Water and Creosote Tanks.		Stone Wagons.				
No.	Average Age.	No.	Average Age.	No.	Average Age.	No.	Average Age.	No.	Average Age.	No.	Average Age.	No.	Average Age.	No.	Average Age.	
	Years.		Years.		Years.		Years.		Years.		Years.		Years.		Years.	
..	..	776	5·19	..	..	..	..	76	11·52	8	1·00	36	5·00	4,210	6·01	1852
..	..	1,136	6·72	..	..	..	..	105	12·10	8	2·00	36	6·00	8,544	6·83	1853
33	1·00	1,136	7·72	..	..	..	..	105	13·10	16	3·00	36	7·00	9,380	7·22	1854
481	1·06	1,136	8·72	..	..	..	..	105	14·10	23	4·00	36	8·00	9,871	7·90	1855
484	2·06	1,136	9·72	40	1·00	..	..	105	15·10	23	5·00	36	9·00	9,920	8·82	1856
684	2·45	1,766	9·82	302	1·13	100	1·00	336	9·07	23	6·00	36	10·00	11,131	8·49	1857
717	3·34	1,789	10·49	302	2·13	100	2·00	336	9·31	23	7·00	36	11·00	11,365	9·17	1858
867	3·75	1,789	11·26	302	3·13	100	3·00	336	10·15	23	8·00	36	12·00	11,517	9·88	1859
1,284	3·32	1,789	12·03	363	3·60	100	4·00	336	10·98	23	9·00	36	13·00	12,520	9·80	1860
2,126	3·13	1,905	12·21	702	2·86	100	4·92	360	10·43	23	10·00	36	14·00	14,620	9·30	1861
2,126	4·13	2,220	12·81	758	3·65	100	5·67	390	11·22	23	10·56	121	12·95	15,961	10·28	1862
2,126	5·13	2,220	13·36	994	3·78	100	6·67	410	11·67	23	11·56	121	13·95	16,227	10·81	June, 1863
2,126	5·11	2,234	13·25	1,052	3·63	100	6·43	414	11·52	23	11·56	121	13·95	16,513	10·51	Dec., 1863
2,126	6·11	2,403	13·23	1,052	4·63	100	7·39	414	12·52	23	12·56	121	14·95	17,101	10·88	June, 1864
2,226	5·88	2,452	12·60	1,052	4·63	100	7·04	421	12·27	23	12·56	21	17·00	17,429	10·31	Dec., 1864

REMARKS.—Up to June, 1863, only those Wagons are included in the Column as having been *rebuilt* which have been entirely new.
The difference in the number of the several descriptions of Wagons between 1856 and 1857 is caused by all the Stock at that period having been classed afresh, re-numbered, and marked "N. E."
In 1862 the Stocks of the Hull and Holderness, and Newcastle and Carlisle Railways are included.

NORTH EASTERN RAILWAY.

STATEMENT showing the TOTAL COST of WAGON STOCK, COST of REPAIRS, COST per VEHICLE per ANNUM, for Repairing and Upholding at the undermentioned Periods.

DATES.	Total Cost of Wagon Stock.	Total Cost of Repairing and Rebuilding.	Per Centage of Repairs and Rebuilding on Total Cost.	Cost of Repairing and Rebuilding per Wagon per Annum.	Cost of Rebuilding.	Cost of Extraordinary Repairs not included under "Rebuilding."
	£. s. d.	£. s. d.	£.	£. s. d.	£. s. d.	£. s. d.
1852	223,270 8 9	10,633 9 2	4·76	2 6 11	.. ..	.. ..
1853	549,731 10 5	30,407 2 5	5·53	3 15 2	.. ..	.. ..
1854	608,972 0 5	44,207 18 8	7·25	4 16 10	.. ..	.. ..
1855	654,687 0 5	43,419 17 3	6·63	4 9 9	.. ..	.. ..
1856	659,292 0 5	42,171 5 5	6·39	4 6 5	.. ..	.. ..
1857	757,128 0 5	49,192 2 7	6·49	4 9 8	.. ..	.. ..
1858	777,354 0 5	46,180 4 5	5·94	4 2 5	5,585	8,955 6 2
1859	792,704 0 5	56,933 4 2	7·18	5 0 3	11,110	14 896 3 7
1860	869,104 16 8	52,382 4 4	6·02	4 4 9	9,766	.. ..
1861	1,064,553 12 5	58,127 13 8	5·46	4 0 5	16,289	.. ..
1862	1,149,223 12 5	75,028 19 5	6·52	4 14 0	23,596	11,635 9 11
June, 1863	1,174,027 12 5	37,212 18 0	3·17	2 5 10	14,449	8,049 3 4
Dec., 1863	1,199,713 12 5	40,804 1 6	3·40	2 9 5	21,042	4,226 11 5
June, 1864	1,253,217 12 5	39.669 7 0	3·16	2 6 4	16,625	9,381 15 7
Dec., 1864	1,284,644 12 5	51,102 14 11	3·97	2 18 8	22,056	8,493 14 9

NORTH EASTERN RAILWAY.

STATEMENT showing the NUMBER, ORIGINAL COST, &c., of the CHALDRON COAL WAGON STOCK, with COST per WAGON per ANNUM for Upholding the same at the undermentioned Periods.

DATES.	Total Chaldron Wagon Stock.	Cost of Repairing and Rebuilding per Wagon per Annum.	Total Cost of Rebuilding and Repairing.	Original Cost.	Per Centage of Repairing and Rebuilding on Original Cost.
		£. s. d.	£. s. d.	£. s. d.	£.
1852	9,039	1 14 10	15,753 2 10	138,545 15 4	11·37
1853	9,506	2 4 11	21,358 17 2	146,484 13 4	14·58
1854	10,050	3 7 3	33,801 9 6	156,400 10 4	21·61
1855	10,050	3 0 11	30,519 5 6	156,400 10 4	19·51
1856	10,050	2 18 7	29,467 3 5	156,400 10 4	18·84
1857	10,050	2 14 9	27,546 13 8	156,400 10 4	17·61
1858	9,901	2 16 3	27.850 13 4	154,165 10 4	18·06
1859	9,496	2 17 6	27,335 2 8	148,090 10 4	18·45
1860	9,239	2 7 11	22,149 10 5	144,235 10 4	15·35
1861	9,251	2 17 4	26,535 7 11	144,633 11 4	18·34
1862	11,872	2 14 8	32,489 18 1	197,053 11 4	16·48
June, 1863	11,872	1 6 10	15,934 6 2	197,053 11 4	8·08
Dec., 1863	11,872	1 9 2	17,349 12 0	197,053 11 4	8·80
June, 1864	11,872	1 9 8	17,599 4 11	197,053 11 4	8·93
Dec., 1864	11,872	1 11 11	18,970 15 7	197,053 11 4	9·61

REMARKS.—In 1862 the Stock of Wagons belonging to the Newcastle and Carlisle Railway is included.

Mr. T. E. Harrison said, in the absence of the Author he would take the opportunity to make a few remarks upon the Paper. It was quite clear that its chief value consisted in the Tables. Those Tables contained the summary of facts as regarded the maintenance of a large rolling stock, amounting in value to a total of $2\frac{1}{2}$ millions, and spread over a series of 12 years; and extending over so long a period they would afford a large amount of information if carefully examined. Members would find some statistics there given in a form which it was probable they would adopt.

On the subject of statistics, he would remark, that it was one which he had felt to be most important in connection with railways. In the case of the North Eastern Railway, not knowing so well what was done by other railway companies in the same direction, it was carried to as large an extent as was practicable, in every department, even in its most minute details; and were prepared, not half yearly, or yearly, but weekly or fortnightly, and laid before Directors, who were thus enabled to see at a moment what was going on, and to draw their own conclusions upon some of the most important points relating to railway management.

These returns not only gave a comparison of one week with another, but of the same period in previous years. They showed at a glance whether justice was being done in the maintenance of the rolling stock. Again, in the case of the locomotive department, these statistics were brought not only before the Board of Directors, but they were submitted in certain details to the men themselves, so that they could test the advantage of one locomotive man over another, down to every item; and the same system was carried throughout the whole railway, from one end of it to the other. It was conducted upon the plan of "a place for everything, and everything in its place." In every department, however small, a printed form was issued, which being filled up at regular periods, showed the whole progress of the operations weekly. His experience of more than thirty years in railway management led him to the conclusion, that it was impossible for any railway company to carry out too strictly, or too minutely, similar returns.

The Author, in these Tables, had endeavoured to lay before the Institution three principles, by which the question of the expenditure of rolling stock might be tested. The first mode was that of taking the age of the stock, in other words, taking the average age of all the rolling stock in the possession of the company. The second mode was by estimating the percentage upon the prime cost of the whole of the stock; and the third, was by taking the cost per vehicle for maintenance.

With regard to the question of the age of rolling stock, or the

age that it might fairly be assumed to attain, there were many elements which entered into the calculation, and rendered it, even with the experience of thirty years, difficult to determine. Referring to the Tables, he found that the age of some of the rolling stock in a particular case, and under peculiar circumstances, was as great as twenty-seven years; but that stock did not at all afford a standard, inasmuch as from its light build its use had been entirely confined to the line for which it was originally built—the old Newcastle and Carlisle Railway: it was designed to travel at a low rate of speed, and with light trains, so that when that railway came into the possession of the North Eastern Company, by amalgamation, it was found impossible to run the stock, except upon its own particular line; and in all probability, if that railway had continued to be the separate property of the company, a large proportion of the stock would have been in existence at the present day, and would have lasted for many years to come. In calculating the age of railway stock he had found, looking minutely into the question, that the number of engines and carriages rebuilt did not arise so much from the fact of their being actually worn out, as from the necessity of replacing some engines by others of greater power and improved construction. The same remark equally applied to the case of carriages. If the first-class carriages of twenty years ago were placed upon a railway now, the public would be anything but satisfied with their comfort and convenience; and the first-class carriages of a few years ago had been by degrees, in almost all cases, converted into second, and in many cases into third class carriages. Therefore looking to the fact that railways during the last twenty years had been, not in their childhood, but in their infancy, it had become a necessity to break up a considerable number of carriages, or to alter them; and to completely remodel locomotives and to build them of larger size to meet the demands of the traffic. It was clear therefore, taking all these circumstances into consideration, that though an opinion of what might be the average life of any description of rolling stock might be formed, when perfection as to the model was attained, it was as yet a matter of speculation. The Author said, that if the average age of all the stock did not exceed one-half of the ultimate life of that stock, justice was done in maintaining it. In the Table representing the locomotive stock (page 483), the upper column gave the ages, commencing from 1852, at which time the number of engines belonging to the company was 209. At that period the average age of the whole stock of engines was 6·81; in 1859 the average age rose to 10·62 years. It then went on to 12·33 years in 1863, and in 1864 the average was 12·75 years for the whole of the stock; therefore, assuming the life of an engine to be 25 years, it was clear, when the total stock was 12·50

years old, it was as near as possible at the point at which the stock ought to be maintained.

He now came to the Table (page 485) which gave the result of the average age of the whole of the carriage stock. This began in 1852, at 8·35 years, and went on increasing to 10·25 in 1862, 10·54, 10·07, 10·37, and 9·75 in the following years. It was clear when the Directors found they were reducing the average age of their stock, which occasionally took place, and when that average age was below one-half the amount of the ultimate age, they were maintaining their stock in a good and efficient state. But an important element in the consideration of this subject was that, in the case of all large railway companies, they were constantly adding new additional stock, and if they added 100 wagons only a year old, that fact tended to reduce the average age of their stock, and was to be considered in estimating the age of it.

The other method was by taking a percentage upon the past cost of the stock for repairs. That had always appeared to him an exceedingly sound mode of calculation. Before entering upon that point he should mention, that in building their engines during the last seven years the North Eastern Company had added about 40 per cent. to the nominal power of their locomotives, merely in breaking up old engines and rebuilding them of a much larger class.

The percentage of repairs, as shown in the Table (page 486), varied from 8·7 to 9·5, then 12, and there was one instance in which it amounted to 14, then it fell to 12. When this was spread over a long series of years, it gave a fair average and a fair criterion of what might be the expenditure. But he would call attention to this fact, though perhaps it was more remarkable in the case of wagon stock, that while in 1860, the total cost of the carriage stock was £209,163, in 1864 it was £284,835 ; therefore the percentage of repairs was a percentage upon a large increase of stock. As regarded the wagon stock, the cost of repairs, as shown by the Table page 489, ran at 4·76, 5, 7, 6 ; and spreading that over 12 years, the average in the cost of repairs was little beyond 6 per cent. ; but, at the same time, it must be remembered that, though the increase of the stock appeared to be large, the whole, or nearly the whole, of that increase was the result of the amalgamation with the Carlisle Railway, and that by the end of the present year the whole would have been entirely rebuilt ; therefore it was impossible not to perceive, when the columns varied during 12 years to so small an extent as these did, that the percentage on the first cost was also in itself a fair test, whether justice was being done to the stock, as regarded its maintenance.

In the Table page 486, relating to carriage-stock, it was shown that in 1852 the cost of maintenance per vehicle, on the average, was only £17 15*s.* 4*d.* In one year it rose to £27 7*s.* 6*d.*, and

in other years ranged at £23 and £25, and in 1864 it was £21 5*s.* 11*d.* There was here a little more variation; but taking the question of the cost per vehicle was another fair mode of ascertaining what the total cost had been.

There was a particular class of stock referred to by the Author, viz. the chaldron coal wagons, in which the percentage of maintenance ran up as high, in some years, as 18 per cent., and in one year 19½ per cent. These wagons were peculiar to the North of England; but still the fact was patent, that upon a stock which was of inferior quality altogether, and not originally intended for the work it was afterwards put to, there was an enormous amount of percentage for maintenance, as compared with the better-constructed class of stock. On the question of whether the stock of the present day was better than that of twenty-five years ago, he did not think any one who had had to do with the maintenance of railway stock could have the slightest hesitation in concurring with the views of the Author. Not only was good care now taken to have a stock of seasoned timber, at least three years old, but the strength of every part of the carriage was now undoubtedly much greater than it was formerly. The strength of the axles, tires, axle-boxes, and bearings, was far more insisted on, as well as the quality of iron used, and these were subjects to which the attention of the carriage superintendent was specially directed; and there could be no doubt, that the comparison was greatly in favour of the stock of the present day. The question now was, what length of life might be fairly assigned to rolling stock on these assumptions, in the first place that a design was obtained from which it would not be necessary to deviate hereafter, and that it would not be necessary, with ordinary repairs, to break up any stock to remodel or improve it? He was sanguine enough to believe that the age might be calculated, with ordinary usage, at not less than thirty years. If the average life was thirty years, and the average age of the whole of the stock, as shown by one of these Tables, was only nine years, or according to other Tables, fourteen years, then the stock was maintained in its full and efficient condition. That, however, was a question on which there were no absolute data, and therefore, he thought, Tables of this nature, and facts gathered by different superintendents, if they would give them, would lead to information which might govern Boards of Directors and superintendents in advising them, upon one of the most important items of outlay which they must incur in maintaining the stock in a full state of efficiency; and on that point, he should be glad to invite information from those who were acquainted with the maintenance of stock, as to what their experience had been.

He would now come to the last part of the Paper, in which it

was stated that the average number of locomotive engines rebuilt during the last three years or four years, was such that it did not show that the stock had been maintained in its full efficiency; but the Author explained that only those engines were included as having been rebuilt, which had been absolutely and entirely remodelled. That was the case with all the engines belonging to the Newcastle and Carlisle Company, which were useless for the purposes of the present traffic. When an engine was rebuilt with cylinders of 18 inches or 20 inches in the place of 13 inches diameter, that was considered as an engine rebuilt; but if an ordinary engine was rebuilt on the old model, it had not been taken into account; and he found, on going through these figures with the Author, that there was a difficulty in knowing when to designate an engine "rebuilt;" but he believed that to add to the complete shell of the engine a boiler and fire-box entirely new, and taking into account so much more that was certain to be done in such a case, amounted to rebuilding an engine. There was one item in the Tables which perhaps required explanation, viz., that of "extraordinary repairs." It seemed to arise in cases where the repairs were carried to an unusual extent in particular cases, and he looked upon it as an attempt on the Author's part to separate the two, without perhaps having any real bearing upon the question.

Mr. HAWKSHAW, Past President, said, when an engine was set aside, and another was built in its place, he called that rebuilding an engine, and nothing short of that would be valuable in statistics of this kind: for if it was left to the locomotive superintendent to make an alteration in the cylinders or other parts, and to call that rebuilding, then it would be impossible to obtain statistics from which any useful deductions could be made. There could be no doubt as to the importance of correct statistics. It would be of great value if every railway company kept the statistics of their rolling stock in the most careful manner, and it would be still better if they would send them to this Institution, and have them recorded. But he was quite sure that, as yet, Engineers were far from possessing any statistics from which it would be safe to generalize as to the duration of a locomotive engine. The Table began by assuming that an engine might last twenty-five years. That was simply an assumption: there was nothing to lead to the conclusion that a locomotive engine would last that period, far less to lead to the supposition that it would last thirty years. Supposing better information was available than was now possessed, it must be applied to each line specially in the first place. The statistics of one line would have little or no application to the statistics of another line. It was with locomotives very much as with clothing. On one man it would be worn out in a short time, and on another it would last longer: so with a railway company

and their locomotives. On some lines carriages twenty years old were still in use, while on another railway no such thing would be found. On the latter managers were compelled to set aside antiquated vehicles long before it was necessary to do so on railways visited by less fashionable people: therefore the statistics of one railway could not be applied to the condition of another. Still it was valuable that each company should possess its own statistics, that they might know all the conditions and consequences under which they were carrying on their traffic. He had studied the statistics of one company as long as his friend Mr. Harrison had those of the North Eastern, but he had not come to any conclusion which he would venture to put forward as to the duration of locomotive engines. Then he objected to the duration of those things being measured by years: there was nothing more fallacious. The life of rails must be measured by the amount of traffic passing over them, and the duration of wheels must be calculated by the number of miles they ran: so, in measuring the duration of the carriages, it must surely be valued by the amount of the work done. Sixteen years or seventeen years ago he entered upon an investigation with a view of arriving at the duration of stock, &c., on the Lancashire and Yorkshire Railway, more particularly with regard to the life of the rails: that was soon after Captain Huish had written his Paper to show that the life of a rail was fifteen years. That was a most startling conclusion, and he set to work to investigate the subject, and he found that the duration of a rail varied from one year and a half up to twenty-five years; and so it must always be. If 10,000 wheels were run over the same rail in a year certain results of wear and tear were produced. If the same number of wheels passed over the rails in twenty years the result would be nearly the same. Still it was open to a particular railway company—for instance, the North Eastern—to say, "We work in the ordinary way with a certain number of vehicles, therefore we may come to a conclusion, that with our usual stock and with our usual mode of working, our vehicles will last so many years;" but if the North Eastern could decide that matter for themselves their conclusion would not fit every other railway. Therefore, while he should be glad to see such statistics brought forward and recorded, so that the members could refer to them, he felt it would be an erroneous thing to say at present, that a locomotive engine would last twenty-five years or thirty years. In time there would be railways carrying the old roadside traffic, perhaps at comparatively slow speeds; others would be worked at higher speeds, and under totally different circumstances; and generalizing was dangerous in the present state of information on this subject.

Mr. W. A. Adams said, during the last ten years or twelve

years he had been much engaged in the construction and upholding of freighters' wagons, and had had under his control as many as 6,000: therefore, with respect to this class of stock he could furnish some statistics to the Institution. The locomotive question he did not pretend to enter into; and he had not had time to investigate that of the carriage stock. The Author's carefully compiled tabular statements opened up a large question, of which the repair and replacement of stock could only form a portion, and one that could not well be treated of by itself. If the matter were examined, it would be found to be the great question of cost of rolling stock per passenger and per ton conveyed. Interest of money and proportion of dead weight to effective load must necessarily form an important element in the estimate of cost of working expenses. He proposed to confine his attention principally to the question of coal-wagon stock, upon which, he had no doubt, Mr. Harrison would be able to assist him with valuable information. It was of little use to know that a railway wagon cost a certain percentage upon its first cost for repairs and replacement; what was required to be known was the percentage of repairs and replacement for the tonnage actually conveyed. Upon referring to the Tables it would be found that the North Eastern Company had (exclusively of the chaldron wagons) the following stock:—

	Average Age.	Cost. £.	s.	d.	Total. £.
504 engines .	12½ years .	2,078	18	2	1,047,770
1,370 carriages .	9¾ „ .	207	18	2	284,835
17,429 wagons .	10⅓ „ .	73	14	1	1,284,644
	Total . . .				£2,617,249

He would be glad to know, whether the 8 ton coal wagons, which were stated to be built of well-seasoned materials, were hopper, or side-door wagons, whether they were buffered, whether the tires were of the best make, and whether the timber was generally well seasoned?

Mr. Harrison replied that the wagons were buffered, had draw springs in every case, and that the Company had generally two years' or three years' stock on hand.

Mr. Adams having recently seen these wagons, believed he was right in saying, that their weight was about 5 tons 5 cwt. for 8 tons of load carried. From the Paper he gathered that the first cost of these wagons was £90 each. The interest of that sum at 5 per cent. would be £4 10*s.*, and repairs and replacement at 6½ per cent. would be £5 13*s.* 6*d.*; total cost of the wagon per annum, £10 3*s.* 6*d*; equal for 17½ years to £178 1*s.* 3*d.*

As against these figures he would quote the experience of the Midland Wagon Company, with which he was connected. Their 8 tons coal wagon cost £60 each, and that was the type of wagon used by private coal-owners. It was a great question with him, whether it was advisable to spend a large sum in first cost, and sacrifice the interest of the money: he thought it better to have a less expensive class of wagon, and save a large sum in interest, and this remark applied equally, whether the wagon had a side door or a hopper. The hopper had the advantage in the economy of repairs. Working out the cost at £60 per wagon, the figures of the Midland Wagon Company for the first ten years per annum come out thus:—

	£.	s.	d.	£.	s.	d.
Interest at 5 per cent. on £60 .	3	0	0			
Average of repairs	3	0	0			
Depreciation laid by	3	12	0 =	9	12	0

At the expiration of ten years there was expended an average of £13 per wagon in replacements, increasing the total cost to £73 per wagon. Thus for the following seven and a half years the figures would stand at per annum—

	£.	s.	d.	£.	s.	d.
Interest on £73 at 5 per cent. .	3	13	0			
Average repairs	3	10	0			
Depreciation	3	12	0 =	10	15	0
or for the 17½ years				176	12	6
Deduct simple interest, calculated at yearly rests, accruing from the depreciation fund of £3 12*s.* per annum for 17½ years . .				26	3	
				150	8	9

which would be equal to £8 12*s.* per annum per wagon, as compared with £10 3*s.* 6*d.*, the cost per annum of the North Eastern Company's coal wagons.

	£.	s.	d.
There would also remain, the depreciation fund, amounting to	63	8	9
And the old wagon, which, if worn out, would as scrap be worth, say 3 tons of scrap iron at £4	12	0	0
	75	8	9

Therefore at the end of the 17½ years, the Wagon Company had, from the depreciation fund for the replacement of the stock and the

value of the old materials, more than the wagons originally cost them.

But there was another grave point in the experience of the Wagon Company. The 8 ton wagons, which were the type of the freighters' wagon, weighed on the average 4 tons 5 cwt.: thus they had a wagon one ton less weight, and if that worked 100 miles per week, the Railway Company saved a draught of 100 tons per week per wagon, and that for 17½ years was equal to 91,000 miles, and at ½*d.* per ton amounted to £189 11*s.* He would cite an example, which told on the question of dead weight. Some years back a coal-owner ran 1000 tons per week in through trains to London, a distance of 150 miles. The wagons weighed 3½ tons each, and the load was 5½ tons: therefore to carry 5½ tons of coal 150 miles, the Railway Company conveyed 7 tons of wagon full and empty 150 miles. The charge per mile for the coal was a halfpenny per ton, or equal, per wagon, to 2¾*d.* per mile, or to 0·22 of 1*d.* per ton per mile of gross load of coal and wagon. His advice to the owner was to get a rate from the Railway Company of 0·22 of 1*d.* per ton for the gross load carried, and he offered to build him wagons which should weigh 3 tons capable of carrying 10 tons of coal. The cost of the coal actually conveyed would then be only 0·35 of a 1*d.* per ton per mile; instead of 0·50, or equal to 1*s.* 10½*d.* per ton, which on 1000 tons per week amounted to no less than £4,875 per annum, for the whole quantity conveyed. That proposal was, he believed, laid before Captain Huish, but was not accepted. His connections with a French Railway Company had gained him considerable experience in French railway rolling stock matters; he found that the proportion of dead weight, as compared with useful weight, was something very different from what it was in this country. In the 8 ton wagons in use on the Western Railway of France, the sole bars and headstocks were 4 inches by 9½ inches, while the practice of the Midland Wagon Company was to have them 5 inches by 12 inches, and the remainder of the wagon in both cases was in proportion. In all their vehicles they considered the proportion of dead weight to paying weight carried. He thought valuable knowledge would be gained if tables were prepared showing the cost of wagons and carriages per ton and per passenger conveyed. On that point, he was sure, railway managers would be glad to receive information.

Mr. J. Gibson remarked, that though these Tables contained much valuable information, they were hardly full enough in details: other columns of results were wanting to make them more serviceable to the Institution. In the statement of the locomotive stock were shown the total cost, the numbers, and the average ages. The figures as to cost were so large that the average cost of

the engines was required, the better to comprehend the quantity, and then the deductions, or in other words the results, would be more fully appreciated. In that Table, the cost of repairs was stated as a percentage upon the first cost, which appeared to go on from year to year regularly and evenly; and he found also, in calculating the average cost of the engines, it was far more uniform than would have been expected, looking at the changes which had been made in locomotive engines of late years, for it began at £1,941 on the average, and left off at £2,078 in the last year. Then, while the average age was 6·81 years, the cost per train mile, for repairs, was stated to be 3·34*d*. The cost was higher as it stood in the Table, when the engine was young, inasmuch as the average cost of repairs of the whole locomotive stock fell in the last year, 1864, to 2·63*d*. per train mile when the average age was 12½ years. The Table of mileages somewhat explained that fact, as, at the later period, there was a little more mileage got out of the engines on an average than at the earlier period; while the average cost of repairs per engine remained about the same. It seemed an anomaly, that while the engines were young, the cost of repairs was comparatively high, and that when they were 12½ years old, and doing harder work, the cost of repairs per mile was considerably reduced. There was a column of "extraordinary repairs," which he did not understand, but perhaps it could be explained.

There seemed to be a desideratum in these Tables, that there should be a measure of the work performed, either in gross load or net work—something to convey to the mind whether the figures of the cost of maintenance were economical or the reverse. On the subject of engines, he would remark that he saw nothing in these Tables to lead to the conclusion, that the life of a locomotive engine might be calculated at twenty-five years. It was an assumption without the demonstration of figures, and it was a matter on which there might be great diversity of opinion. He thought there might be circumstances which would entirely put aside any calculations on this subject on which to base an average. The stock of a railway might be doubled within a few years, and the older part of it, though the age might come within the proposed limit, might not all be done justice to; so that, time was not the proper criterion to indicate the state or condition of the stock.

Passing from the engine to the carriage stock, he thought the Table of ages was too general to be of much practical use. In cases where the relative proportions of the different classes of the carriage stock remained much the same, an approximate result might be obtained from year to year; but for general use and for comparison he thought a more detailed statement of the results in each class of the stock was wanted; for instance, by taking first, second,

and third classes by themselves, and showing a rate for each per passenger train mile rate. A vague idea might be obtained from these figures, but the passenger train stock was so various, and the proportionate number of each class of vehicles in a train so differed on different railways, that it was not a good measure for general application. Then with regard to the average cost of the vehicles. It began in 1852 at £186, and went on increasing to £207 in 1864. Whether that difference arose from an alteration in proportions of the classes, or from the introduction of superior carriages of a particular class, there were no means of judging. The percentage of 11·26 on the cost price for the maintenance of that stock was, he thought, rather a high one; 7·95 or 8·00 was about the average of the Great Western carriage stock. Taking goods and passenger trains together, the percentage of repairs on cost price was, on the North Eastern 7·75, and on the Great Western 7·52.

With regard to the wagon stock, it seemed to have increased in price considerably, from the first year down to the last. In the first year the average cost was £53 per wagon, and in the last £74. That was a large increase, and whether it arose from the introduction of a superior class of stock, or from a rise of price in the market, there was nothing to explain why the price should have gone up in twelve years from £53 to £74; and with a large wagon stock like that of the North Eastern, this Table might be usefully subdivided, so as to give more practical results than could be gained by aggregating them. Then there was the question, whether these figures of cost included the wagon sheets, as was the case in the accounts of some companies.

Another Table of useful particulars would be afforded by setting forth such repairs as were incurred by damages from accidents and from collisions. Those were matters over which the superintendent of the department had no control, and in case of any extraordinary excess of repairs, the damage from accidents might be brought forward in extenuation, or in explanation so far, of such excess. In conclusion he would say, it was essential that the measure of the capacity of the coal wagons should be stated, since it was impossible to compare the results on this railway with those on any other, apart from the knowledge of the respective capacity of the wagons.

Mr. G. P. Bidder, Past-President, said, he desired to commence the few observations he had to make by paying a tribute of praise to the Author for compiling any Tables at all. They were not perfect Tables, but certainly they were the best the Institution had ever had, and they had led to a discussion of the greatest importance, one which ought to have been entered upon long since, and that was, on the actual cost and maintenance of railway rolling stock.

It was a subject of vital importance in any question regarding railway politics; it would become of still more vital importance in respect of that Commission which was now established, for the consideration of what might be the government operation upon railways in this country. It was true that there were some points in the Paper with which he did not entirely agree, and that the Tables were not so explicit and full as he could wish, or sufficiently demonstrative, and he hoped (for it would be a most gratifying result) that these were only the forerunners of more satisfactory Tables; but they were, he repeated, the best that had yet appeared, and they had laid a foundation for considerations of the highest importance in regard to railways. Therefore in any remarks in which he might venture to differ, in some respects, from the results of the Author, he did so with the most perfect respect, and with great gratitude for the information which had been submitted in so unpretentious a manner.

The discussion was one which ought not to be entered upon in a dogmatical spirit, nor with the conviction that the question was incapable of solution. This, like many other problems, was one in which it would be wrong to predicate the result of any particular fact; so large a question required large averages, just as in the case of life and fire assurance. There was no one single fact that ever came actually right, there was no one single life which had been insured, or any annuity which had been granted, that came true to the calculated tables. Nevertheless, by taking large averages, the result always justified the calculations, when they were based upon the satisfactory data of experience. Although Mr. Bidder might point out what occurred to him as the approximate results to which, as far as he could judge, or so far as his experience pointed, he begged at once to say that, however strongly he might express himself, he did it, not in a dogmatic spirit, but solely with the intention to invite discussion, and because he believed, if this matter was pursued honestly, and with a sincere desire to elucidate the truth, it could be brought within simple and manageable data.

He had had occasion (in regard to the economy with which raw produce—coal for instance—could be conveyed) to ascertain specially the cost at which railways could be worked. He had taken a great deal of pains, and had analyzed the Board of Trade returns, and all he could say was, that those who entered upon that investigation would find it sufficiently complicated. It would be an easy matter if these returns were made out upon one basis and one system, but they were not; and they required a tedious analysis to know in what way they were based. Some gave the mileage of trains run empty; some gave the mileage of trains full and empty; while some gave the mileage including shunting

and piloting; and with regard to the Tables of the Author, he gave the mileage run by the engines, but did not say whether when running empty, or full, or including shunting,—a work on a system like the North Eastern, in the collection of coals from various collieries, which must be exceptionally large. Mr. Harrison had stated that this was the gross mileage, and therefore it was not complete unless it was known how much of that was due to trains actually earning money; for a train which was carrying a full load of coals to a station and returning empty, was not earning money both ways, and the results should be divided by 2; therefore these Tables, truthful, accurate, as no doubt they were, did not contain sufficient details, but were the means of directing attention to normal results which were well deserving of careful consideration.

In the year 1849, as Engineer of the North Staffordshire Railway, Mr. Bidder ventured to attempt to do that which he was told he could not do, that was, to make a contract for the maintenance and working of the rolling stock of that railway. He prepared a specification which was put up to public tender, and for which a variety of tenders were sent in,—that of Messrs. Wright being accepted. It worked for ten years, and at the end of that period it was wound up without difficulty or altercation, but Messrs. Wright did not desire to continue the contract. That contract he proposed because he believed it was based upon sound data; one main principle applied to it being, the maintenance and repairing of the locomotive stock. Even at that time, in 1849, though a great advance had been made in locomotive engines, they were not of that power, and of that perfection of proportion and workmanship, which were characteristic of the machine at the present day; but he estimated the life of a locomotive engine not by measure chronologically, but by the measure of the miles it travelled: he had put that measure at 300,000 miles, and the renewals and current repairs at $1\frac{1}{2}d.$ per mile: he had put that figure advisedly a little above what would be the actual amount, in order to represent the cost of an engine of £1,875. The result of that contract was this—that he had said, when it expired, Messrs. Wright did not desire to continue it; and yesterday (it was six years since the contract lapsed) he ventured to ask Mr. Wright to explain the real facts, the result of that contract: "Well," he said, "for the first few years we were out of pocket; but as the traffic of the line increased it recouped us our loss, but still left us with so little margin of profit, that considering the responsibility involved, we did not think it desirable to continue it." Now that contract was designed advisedly with the intention that when the traffic was small, the payment should be small; and

when the traffic increased, and the company was more prosperous, it could afford a larger margin of profit to the contractors. It so happened, that in its early years the North Staffordshire had a sparse traffic, and the contractors were out of pocket; but towards the end of the contract the loads increased and they were recouped; therefore, compatibly with the nature of the stock, that contract had tolerably approximated the actual cost of repairing and maintaining the rolling stock: and though it was felt, that a contract for maintaining rolling stock involved so many considerations that it was always despaired of, yet that contract was carried out. Mr. Bidder was not laying down any general rule, because the repairs of the rolling stock of a line like the Metropolitan, earning £30,000 per mile per annum, could not properly be compared with a railway in a remote rural district, or a branch line, earning only £300 per mile. It would not apply; therefore he was doing no more than laying down what appeared to him to be the results to which experience pointed, as applied to large systems; and those systems, even, were to be discriminated. The London and North Western being a mineral line, the Great Western becoming a mineral line, the Midland, perhaps the most important mineral line of all; next to that was the North Eastern; then the Great Northern, and then the Great Eastern. But there was one circumstance which this investigation had served to show; viz., that there was an absolute relationship between the revenue, the mileage, and the cost of the rolling stock. Now, he believed, it would be found very nearly that the working value of the rolling stock of any railway would be represented by the gross annual revenue; in other words, if a railway was earning a million a year the value of the rolling stock should be one million; and there was this fact also;—that the earnings of the trains, eliminating pilotage and shunting (but the earnings of the trains in practical operation approached 5*s.* per mile), varied from 5*s.* 3*d.* to 4*s.* 3*d.* and 4*s.* 2*d.*, as upon a mineral line where the working expenses were correspondingly less. This result would also be found, that the cost of the locomotive stock and the cost of the carriage and wagon stock were as near as possible the same; that was, when a million of revenue had to be earned, composed of passenger traffic, goods traffic, and mineral traffic, there would be a million's worth of rolling stock—half of that amount being represented by locomotives, and half by carriages and wagons; and that, taking the earnings at 5*s.* per mile, this result would be arrived at:—that every locomotive engine ought to earn £5,000 per annum, and that the carriage stock should also earn £5,000 per annum. Some of the figures were taken from the Board of Trade returns, but he would take the returns given by the Author from his Tables. The value of

the locomotive stock was found to be £1,033,000; and that of the carriage and wagon stock, £1,567,000; *i. e.* in round numbers, £2,600,000, including the Stockton and Darlington stock; and that with the Hartlepool stock, about half a million, would make a total of £3,100,000. Mr. Harrison would admit that that was nearly the amount of the gross income of the North Eastern Railway. Then there was the Great Eastern. Last year the trains ran 6,480,000 miles: that was actual train miles, not including shunting and piloting, but actual train mileage; the receipts were £1,638,000; but that stock and mileage included the working of the Tilbury and Southend, the Lynn and Hunstanton, and the Ware, Hodham, and Buntingford lines, bringing up the receipts to £1,700,000. 6,400,000 at 5*s.* per mile, was £1,620,000, and that was the present working value of the Great Eastern stock, approximately. He had also seen what the repairs were compared with the North Eastern. The actual expenditure on the former in current repairs was £61,000 for locomotives, and £58,000 for carriages and wagons; and this inference was to be drawn from that which ran through all experience—that the current repairs of engine, and carriage and wagon rolling stock were always nearly the same in amount per annum. It was so accidentally. No man could predicate that from any *à priori* considerations, but it was the result of experience, and that being so, it was an important fact to bear in mind in the consideration of this important question. The total of these current repairs amounted to £119,000. Mr. Sinclair and himself, some three years ago, conferred together to know what would be the amount, in addition to that which ought to be deducted from revenue, to uphold the rolling stock in its original value, and it was found to amount to £25,000 per annum for locomotives and £29,000 per annum for carriages and wagons, making an aggregate of £173,000 a year. Now when that result was compared with the experience of the Author, instead of £173,000 it should have been £145,000; there was a disparity of £28,000 between actual expenditure and that which would have been, if corresponding with the results established by the Author's Tables. No doubt the North Eastern Railway had advantages in regard to wages, advantages also in regard to cost of fuel, as also in regard to that of iron; but those probably did not represent, to the whole extent, the £28,000 per annum. Probably—though it was mere conjecture—about half that amount would be the fair proportion, and therefore there was ground for thinking, that the Author was charging his stock with too little maintenance. In the Paper it was stated that there were 504 engines in 1864; that these engines ran 12,000,000 miles; or 24,000 miles per annum for each engine: that was a large performance, for, according to ordinary expe-

rience, the performance of an engine was not more than 20,000 miles per annum; therefore it was probable that these engines might have been overlooked, and that some part of the discrepancy might be attributed to that cause. Then a sum of £29,000 was placed to the account for carriages, and £91,000 a year for wagon stock, making a total of £246,000 a year as the expenditure of maintenance, and for upholding the locomotives, carriages, and wagons; and that amounted upon the mileage to a small fraction under 5*d.* per ton; while the actual expenditure of the Great Eastern upon 6,480,000 miles was £173,000, or about $6\frac{1}{4}d.$ per ton: part of that was, no doubt, to be attributed to the fund set aside for renewals.

That question required a moment's examination. In 1849, he considered that the life of an engine was measured by 300,000 miles; that was to say, after paying for repairs that was what it amounted to; it was equivalent to having a life assurance on the engine, which expired at 300,000 miles; the premium upon that assurance might be put at $1\frac{1}{2}d.$ per mile, which was undoubtedly high; but the contractor who provided rolling stock was obliged to pay into the company an equivalent, and he could only withdraw it by putting a locomotive upon the line; therefore it was to his interest to do so, and to maintain the rolling stock in the highest degree of efficiency.

The life of a locomotive engine might now certainly be estimated at more than 400,000 miles, and that at the expiration of its life —because as long as it was in use it was supposed to be capable of running,—was worth something. If the price of an engine was £3,000 (not an excessive sum for the power now developed, the prices ranging from £2,700 to £3,500), £2,000 of £3,000 ought to be set aside, to be appropriated as renewal: when incapable of further duty, its value would represent $1\frac{1}{4}d.$ per mile: that was a safe estimate, and less would not be safe: it was certainly less than the amount set aside by the Author, because $1\frac{1}{4}d.$ per mile upon his mileage would be £62,000 per annum, whereas the amount he had set aside for locomotives was £126,000. That was a fair question for discussion, and it was to be hoped he was right, because the more cheaply a line could be worked, the better it was for those who made and had the maintaining of railways.

There was another question not alluded to in the Paper, which Mr. Bidder hoped would be treated of in the next session, viz., railway accounts, because the great object of the Paper was to enable railway companies in their annual, or half-yearly accounts, to set aside that fair and proper amount which should serve to keep up their estate; *i. e.*, that revenue should be so represented by stock, or money, that at the end of the year the rolling stock should represent its value at the beginning of the year. But there was

another part of the estate which had also to be maintained—the permanent way, which consisted of two or three materials, each subject to different laws—the ballast, the sleepers, and the rails. The ballast, as all were aware, gradually became attenuated by attrition, but that was always met by replacement out of revenue, with more, or better ballast. Then there were the sleepers, which, whether trains ran over them, or not, were always in process of natural decay. There had been various ingenious inventions for prolonging the life of sleepers: there was Kyanizing, which was a perfect process when honestly applied; there was Burnetizing, also effective for the purpose when properly applied; and there was also creosoting. The life of sleepers had been variously estimated. Mr. Sinclair, of the Great Eastern, calculated it at twenty years for good sleepers well prepared, and these were always replaced half-yearly out of revenue. Then come the rails, and, with regard to them, to a great extent the question of natural decay might be put aside. No doubt if a train never passed over the rails there would be rust, and probably greater absolute waste than with use: the rust would act more severely on them than actual attrition from the wheels of trains, in the course of ordinary traffic. But in practice that was not the case which had to be dealt with, but rails in moderate use; and after discussing that question with Mr. Sinclair, the result arrived at was, that $\frac{5}{8}$ths of a penny per train per mile would represent the absolute wear upon the rails; or, that in about twenty-five years the rails would have to be renewed. Then there remained, not a material like sleepers, which was utterly valueless, but, out of a rail originally 75 lbs. to the yard, there were 70 lbs. of material left, and the only cost was that of replacing it, or re-rolling it; and Mr. Sinclair agreed with him that the proper amount for replacement of rails represented $\frac{5}{8}$ths of a penny per train mile.

Mr. Bidder had thrown out these observations, not with a desire that they should be accepted as conclusive, but as pointing out results which he believed, whether they established those he had mentioned or not, would, if these things were once founded on clear, indisputable data, prove that if the gross revenue of a railway was a million per annum on large systems, the value of the rolling stock would be, approximately, a million of money: its maintenance would be found to be something like £100,000 a year, or 10 per cent.; the earnings of the trains would be something like 5*s.* per mile; the earnings of the locomotives would be £5,000 per annum; the amount to be set aside for the reparation of the rails would be $\frac{5}{8}$ths of a penny per train mile. The Institution was not asked to accept these data as conclusive; but if these Tables were carefully followed up, and if other gentlemen would give the profession the benefit of their

experience, he believed it would be practicable to arrive at some clear and conclusive data which on general questions would be safe guides.

In conclusion, he might mention, to show how various were the results in the accounts of railways, that Mr. Craig, the most experienced man, perhaps, in this country as regarded the valuation of railway stock of every kind, had furnished him with the following Table :—

AVERAGE COST of maintaining Engines, Carriages, and Wagon Stock, on the following Railways, viz.—

RAILWAYS.	Cost of Repairs of Engines per Train Mile.	Cost per Carriage per Annum.	Cost per Wagon per Annum.
	d.	£. *s.* *d.*	£. *s.* *d.*
East Lancashire Railway, 1857	2·73	20 19 $2\frac{3}{4}$	4 2 $6\frac{1}{2}$
Lancashire and Yorkshire Railway, 1857 .	2·35	15 12 1	3 10 0
Glasgow and South Western Railway, 1857	2·6	..	..
Scottish Central Railway, 1857[a]	2·35	12 14 0	5 8 4
London and North Western, Southern division	..	23 7 0	6 18 10
Birkenhead, Lancashire, and Cheshire Junction, as taken from their published accounts	..	14 0 0	2 5 4
Manchester, Sheffield, and Lincolnshire Railway, average cost for five years, ending June, 1858	2·97	20 8 0	3 18 2
Ditto ditto per Engine per annum, for repairs for five years, ending June, 1858 .	£. *s.* 245 19		

[a] Mr. Allan, of the Scottish Central, states that £5 8*s.* 4*d.* is nearly double their usual average.

It showed, that the East Lancashire Company in 1857 set aside $2\frac{3}{4}d.$ per train mile as the cost of the engine, £21 for the carriages, and £4 2*s.* 6*d.* for the wagon stock; but on the Lancashire and Yorkshire, instead of $2\frac{3}{4}d.$ the cost was 2·35 for engines; instead of £21 it was £15 12*s.* for carriages; and instead of £4 2*s.* 6*d.*, it was £3 10*s.* for wagons. The Glasgow and South Western had $2\frac{5}{8}d.$ for engines; the Scottish Central $2\frac{3}{8}d.$, £12 14*s.* for carriages, and £5 8*s.* 4*d.* for wagons; while the London and North Western had £23 7*s.* for carriages and £6 18*s.* 10*d.* for wagons—evidently a large amount.

There were anomalies in this Table which he was quite certain it would be easy to reconcile; but the great question was, how much should be set aside for renewals; and even that quantity

depended upon this—how much more thoroughly the current repairs were entered upon by one company than by another. They might defer current repairs: they might defer painting and reparation of tubes and various other matters, and throw them at last into renewals. Therefore it was necessary to take the whole question. He believed Mr. Gibson would tell him, in regard to renewals of locomotive stock, that the Great Western had this advantage—they had unusually large engines with unusually large boiler and fire-box capacity: the consequence had been, there had not been the necessity of firing so intensely as in engines of smaller relative capacity; and it was established that in locomotives, or in marine boilers, the less the intensity of firing, the longer would be the life of the boiler. These were all questions of importance which should be discussed, and these few remarks were thrown out in order that when this question was discussed again, data should be provided on which to lay down certain reliable principles.

Mr. Bidder mentioned, that M. Talabot, a French Engineer connected with railways on the Continent to a greater extent, probably, than any other man, had communicated to the Hon. Secretary, Mr. Charles Manby, the fact that the average life of a French locomotive engine was only about 250,000 miles, while Mr. Bidder estimated the life of an English locomotive engine at 450,000 miles.

Mr. T. E. Harrison, in reply, said, he thought (though he had not the exact figures with him) that the wages of fitters, and workmen generally, in the North of England, were at least 15 per cent. lower than the wages paid in and near London. That no doubt accounted for a large proportion of the difference of cost between the North Eastern and the Great Eastern. It had been justly said that these Tables would not be found perfect. He should be exceedingly glad if Mr. Bidder, or any other member, would prepare a form of Table embodying the additional information suggested, which would be not only applicable for his purposes, but applicable also for all those who chose to use them; and he was quite satisfied that there was not the most minute detail which had been suggested as necessary to complete these Tables, which did not exist in the documents belonging to the company.

Reference had been made to the slightly increasing value of the locomotive stock. The peculiarity of the Tables as to the value of the stock, not only locomotive but carriage and wagon, was this—that a number of the engines marked as being in existence now were made in the year 1834. That was going back to a period when £800 or £850 was considered a large sum to pay for a locomotive engine; and those sums, which were the first cost, had remained in the stock-book of the company as their value up to this day, though many of them had been replaced out of revenue,

by engines which cost £3,500: therefore the average prime cost of the locomotives was undoubtedly there shown below what the original cost would have been if built as they now existed. The same general remark applied also to the other classes of stock. The total mileage of the engines was between 24,000 miles and 25,000 miles per engine per annum. He agreed that that was above the average, as he had always calculated the average work of an engine at not more than 20,000 miles; but he believed the stock, in proportion to the number of engines in steam daily, was somewhat below the average of other companies; and from the great pressure of business, and the demand upon the engines, it had not been an unusual thing, during the last three years or four years, for some of the engines to be worked with double sets of men. Of course that was not an economical mode of working; but when fifty additional engines were wanted, every locomotive manufacturer was so full of orders, that instead of getting them in six months, it was necessary to wait two years, and in the mean time the stock on hand had to be worked at a disadvantage.

With regard to the fire-boxes, on the last 183 replaced, the average mileage run by engines was on 150,000 miles: out of 155 sets of tires the average mileage run was 90,000 miles: out of the last 635 crank-axles the average mileage was only 102,000 miles, the life of some of the crank-axles being less in places where there were sharp curves. The difficulty of estimating the period of life of an engine arose from the circumstance of the repairs of these essential features of an engine occurring more rapidly than in other portions of the engines. Taking boilers as a test, he found the average had been 330,000 train miles to 340,000 train miles as the life of the boiler. During the first twelve years after an engine was run, the average expenditure for the items mentioned above amounted to £2,500 per engine, and when an engine had got its new boiler, it was, for all practical purposes, quite as good as a new engine; but it was not considered in this Table that, when an engine was so rebuilt, it was a new engine, but only when a new engine was built to replace an engine of an old-fashioned form. If he might judge from the statement made by Mr. W. A. Adams of the amount he laid by for depreciation and repairs on his wagons costing £60, and receiving about £10 a year as the rental, these wagons must be exceedingly profitable. If from the time a wagon was put upon the line it cost for ordinary repairs £3 per wagon, it was a result opposed to all experience. As to the larger class of 8-ton wagons, the cost was £90; but there was this peculiarity in the North Eastern district, that from the fact of having these chaldron wagons, not only were the coal but the goods wagons necessarily fitted with extra buffers, and that added not only to the weight but also to the cost. There

were very steep inclines to work, and double brakes and brake-handles were required on both sides of the wagons, which involved an additional cost of £6 per wagon; and though this might be considered a refinement of expenditure, yet in a case where there was a risk of a large amount of breakage, he apprehended it was justifiable to apply it to that particular class of stock. Deducting, then, these items of extra construction, it would bring the cost down from £90 to about £74 15s., as compared with the wagons at £60.

Having looked carefully into this question, he was satisfied that there was no more important point in the construction of this stock than using well-seasoned timber. The Tables showed in regard to one particular class of wagons, that the number had been diminished from 300 to about 200: that was, 100 had been rebuilt, and those wagons were only about eleven years old, and there were 100 more of the same wagons now coming in for rebuilding. They were built by contract, and were required for an emergency, and having been made of unseasoned timber they lasted but a comparatively short time. He hoped he might be allowed to convey to the Author the opinion of the Institution as expressed by Mr. Bidder, that the Tables had afforded some data for the future; and he trusted that next session more perfect Tables would be presented, as he was satisfied that any information based upon sound data would be held to be of great value by railway shareholders generally.

May 23, 1865.

JOHN FOWLER, Vice-President,
in the Chair.

The discussion upon the Paper, No. 1,132, "On the Maintenance of Railway Rolling Stock," was continued throughout the evening, to the exclusion of any other subject.

The following Candidates were balloted for, and duly elected:—THOMAS NESHAM KIRKHAM, WOODFORD PILKINGTON, and CHARLES ROBERT SWYER, as Members; ALEXANDER AIRD, JOHN BARTON, JAMES BROADBRIDGE, WILLIAM ALEXANDER BRUNTON, WILLIAM CAWKWELL, DAVID COGAN, WILLIAM HARKER, CHARLES HASLETT, SAMUEL FURNESS HOLMES, JAMES LEMON, EDMUND MOREL, EDMUND ALFRED PONTIFEX, ASTLEY PASTON PRICE, Ph.D., HENRY SADLEIR RIDINGS, GEORGE NAYLOR VICKERS, FRANCIS WILLIAM WEBB, EDWARD ROMILLY WILLIS, and ISAAC WILSON, as Associates.

May 30, 1865.

The Session was concluded by a Conversazione, at which the President received the Members of the Institution, and a numerous circle of distinguished visitors. The rooms were decorated with many choice works of art, and there was also exhibited a large and interesting collection of mechanical models.

APPENDIX TO VOL. XXIV.

Reports referred to in Mr. Hawkshaw's Remarks on the Main Drainage of London, *ante* page 331.

I.—Report from the Committee of the Metropolitan Commission of Sewers, on the Plans for the Drainage of London:—

"We have, pursuant to the Resolution of the General Committee of the 15th December last, carefully examined and considered the whole of the plans and suggestions for the drainage of London submitted to the Metropolitan Commissioners of Sewers, and we now proceed briefly to state, for the information of the General Committee, the principal conclusions at which we have arrived upon the subject referred to us. These plans, it may be remarked, were not sent in upon the invitation of the present Commission, and it is probable that, were we now called upon to deal with the drainage of London as an original question, and wholly without reference to previous proceedings, we might reflect that a well conceived and maturely digested plan of general drainage could not be framed without a larger stock of local information of an accurate and specific character, than could be collected by the unaided efforts of individuals, or made accessible to them, without undue expense and inconvenience.

"The effect of this deficiency of the necessary information has become apparent in several of the schemes submitted to us, which, though well conceived, so far as regards their general features, are wholly inconsistent with the levels and other natural conditions of the localities, to which they are intended to apply. We have made every allowance for the disadvantage, to which the authors of the schemes were thus subjected, and wherever an error did not lie at the root of the system, but was merely one of detail, we have disregarded it, and endeavoured to give full effect to the suggestion of the author. The plans may be conveniently distributed under the following divisions:—

"1. That which may be designated as the Portable Cesspool System, by which it is proposed, that each dwelling-house should be furnished with a portable iron or other vessel or receptacle for fæcal matter, which is to be periodically removed to depôts, situate in the suburbs of the Metropolis, whence it is to be distributed in the form of manure for the purposes of agriculture. It is an essential condition of this class of schemes, that as little water as possible should be allowed to mingle with the solid sewage matter, in order that its fertilizing power should not be diminished, and that its augmented bulk should not oppose obstacles to its convenient removal and transport.

"2. The schemes included under this division contemplate the discharge of the whole drainage of London into the Thames, and the maintenance of the present system of outlets, though under improved conditions. The projectors contend that the river is the natural and only legitimate outlet for the sewage of the Metropolis, and place reliance upon the effect of an increased supply of water, so abundant as to insure an almost unintermittent current in the sewers, by which it is assumed that the sewage matter will be extensively diluted, and its effect upon the vast body of tidal water rendered scarcely perceptible. It is also a distinguishing feature of these schemes, that the outfalls of the sewers

are intended to be carried out to or beyond low-water mark, and generally into the middle of the river.

"3. The authors of the projects included in the 3rd division propose to lay down tunnels or culverts of iron, brick, or other material, in and along the mud-banks of the Thames, and occasionally in or under its bed, for the purpose of intercepting and receiving at the various outlets of the existing sewers the drainage of the districts on each side of the river. These culverts or tunnels are generally continued to the marsh grounds in the county of Essex, beyond the river Lea, on the north side of the Thames, and to Plumstead Marshes on the south, at which points reservoirs and filtering-beds are to be formed for preparing and rendering portable the sewage matter for manure.

"4. The fourth division differs from the preceding one in this particular, that, instead of having a single intercepting sewer at the lowest level, it proposes several of such sewers at progressive ranges of altitude, determined by the various drainage areas, with the view of preventing the refuse of the higher portions from descending to and encumbering the flat districts below. In the great majority of these projects these lines of intercepting sewers are conducted to points in the marshes to the east of London, at a lower level than low water, in consequence of which it becomes necessary to employ steam power to pump up the refuse.

"5. The fifth division involves the establishment of cesspools at the outlets of the principal sewers along the banks of the Thames, it being the intention of the framers of this class of plans to unite several of these outlets into one, according to the conditions and requirements of particular localities; and, at these points of union or concentration to erect pumping apparatus of great power for conveying the sewage matter into the rural districts, either through iron pipes, or by means of carts, barges, or other modes of transport.

"6. This class has for its object the division of the Metropolis into separate drainage areas, in the centres of which it is proposed to form sumpts, or pits, for the reception of the sewage matter, from which it is intended to be pumped and distributed by various methods, for the most part similar in character to those adopted in the case of the schemes described under the last division.

"7. This division includes a numerous class of projects, which, with scarcely an exception, instead of being directed to the object of making provision for an improved system of general sewerage, are almost exclusively confined to the consideration of processes and expedients for infiltrating, deodorizing, and solidifying the sewage matter for the purposes of the farmer and market-gardener.

"In addition to schemes involving definite characteristics, and susceptible of some species of classification, numerous communications have come under our notice which may, for the most part, be described as vague speculative disquisitions on collateral and subordinate branches of the general subject of drainage, few of which can be said to possess any practical value. It is observable that the great majority of these schemes adopt, as an essential principle, the diversion from the Thames of the great mass of London sewage matter now discharged into it, an object which it appears to us to be most desirable to accomplish to the greatest practicable extent. We also assent to the views of those, who are opposed to the separation of surface and house drainage. We think it objectionable, generally, to bring down the drainage of the high grounds to the lower districts; and we agree in the opinion, that it is of paramount importance to make every effort for accomplishing the drainage of London by natural means; that machinery should not be employed generally, or on a large scale; and that it should only be resorted to in the last instance, and under special circumstances, as in the case of detached and insulated districts limited in extent, and so situated as to render it a matter of undue difficulty to unite them with others.

"In expressing the results of our examination of these plans (which is the task entrusted to us), we take the opportunity of remarking, that it is not proposed, in the course of the present observations, to exceed the limits of that task, or anticipate the decision of the Commissioners, as a body, by laying down the system, which it may be advisable for the Commission to adopt in discharging one of the main duties confided to it; that is to say, in making provision for the effectual drainage of London.

"With this remark we proceed to enumerate those among the plans submitted to us, which appear deserving of special mention, and briefly to describe some of their more prominent features, referring, for a fuller account of their scope and objects, to the expositions of them furnished by the authors themselves, to the descriptions which accompany them, the printed statements in the possession of the Commissioners, and to the Classification of them appended to this Report.

"The best conceived and most practicable scheme submitted to the Commissioners, is, in our opinion, that of Mr. J. R. M'Clean; and though we do not deem ourselves justified in recommending any one of these schemes for adoption, as a whole, we yet think that Mr. M'Clean's plan contains many of the main elements of a sound and judicious system of drainage. It is characterized by a well-devised system of intercepting sewers, in determining the situation and course of which a careful and elaborate study of the levels has evidently been made. These intercepting sewers generally follow the direction of the main thoroughfares, and avoid any extensive interference with private property.

"The chief of them, on the north of the Thames, commences near Battle Bridge, and, after running a course of nearly eight miles, terminates at the river Thames, at some distance below the river Lea.

"There is, however, one portion of the Metropolis, namely, the long narrow tract lying on the north margin of the Thames, between Charing Cross and Shadwell, for which sufficient provision does not seem to be made. It is not made apparent whether it is proposed to resort to pumping for the drainage of this part of London; but with regard to a large proportion of the tract in question, no other expedient would seem to be applicable.

"The lower districts of Westminster are treated in a somewhat peculiar manner,—namely, by carrying an iron syphon across and underneath the Thames above Vauxhall Bridge. This portion of the scheme involves great difficulties, and we consider it decidedly objectionable: but it must be borne in mind that it proposes to deal with the drainage of Westminster (confessedly a difficult subject) without the aid of a pumping apparatus, or a deep tunnel, or of a discharge into the Thames, as at present. While pointing out these objections to the scheme, we think it just to direct attention to the comprehensive arrangement of the intercepting drains, and to the judgment displayed in the mode adopted for finally disposing of the sewage of a great proportion of the Metropolis by natural means: and though it leaves full scope for any operations designed for the preparation of sewage matter for agricultural purposes that may be proved to be advisable, it does not render the efficiency of the entire scheme dependent upon the success of such operations. Neither can we omit to notice the great labour, care, and skill which have been brought to bear upon the preparation of the plans and sections, by which the exposition of the project is accompanied; the sections evincing a most elaborate study of the existing sewers, and of the means available for blending them with the extended improvements the author proposes. It is an important feature of the plan, that, except in the instance above referred to, the drainage is effected without the use of pumping, and it is not improbable that the main features of it will be found in accordance with the principles, which it will be deemed proper eventually to adopt.

"Though the praise of having framed a design for the drainage of the

Metropolis, possessing a certain degree of unity and consistency, and capable, with partial modifications, of being carried out according to its general scope and conception, appears to us due to Mr. M'Clean alone, among those who have contributed the plans under our consideration, four other plans have come under our notice, each possessing, according to the particular views and intentions of its author, an amount of merit in individual portions of it, justifying a special notice of them. We allude to the plans of Messrs. Nasmyth and Statham, Mr. J. Bailey Denton, Mr. J. Phillips, and Mr. H. Austin.

"The plan of Messrs. Nasmyth and Statham, and the descriptions which accompany it, only have reference to the south side of the Thames; but the authors state they have also directed their attention to the north side of the river, and are prepared to present details of that portion of their plan. Their system on the south side consists of a deep main sewer, from the neighbourhood of Battersea Bridge, extending through Kennington, Camberwell, passing under Deptford Creek by means of a cast-iron syphon, and terminating at the Greenwich Marshes. Into this it is proposed that the sewers of Lambeth, Southwark, and Bermondsey should discharge themselves, water entering them from the Thames at or near high-water mark.

"This plan is characterized by merit in many of its details, and has evidently received much attention. It is somewhat similar in its general features to the project of Mr. M'Clean and Mr. Bailey Denton, with reference to the same localities. But the objects proposed by the authors are, we think, capable of being effected by less complicated machinery.

"Mr. Denton proposes high-level intercepting sewers, to terminate at places conveniently situated for reservoirs, and the employment of the sewage matter for agriculture; to convey by two low-level drains, one north and the other south of the Thames, the drainage of the lower part of the Metropolis to Plumstead Marshes and Barking Creek. He intends to obtain a large supply of water from the Thames, a little above Boulter's Lock, and another from the river Colne. The northern portion of London is supposed to be divided by the Fleet Ditch. The sewage of the portion west of the Fleet Ditch is drained by two intercepting sewers, leading towards the west to beyond Bayswater, where a junction is formed with a large drain running from Brentford to Plumstead Marshes, crossing the Thames by a syphon under its bed, between Vauxhall and Westminster Bridges. The part of the Metropolis lying east of the Fleet Ditch is drained by three intercepting sewers, which unite near West Ham and extend to a large depôt at Barking Creek.

"Mr. Denton's observations evince considerable practical discernment and knowledge of the subject; and his project indicates that much attention has been bestowed upon it. In its general outline it bears some resemblance to that of Mr. M'Clean, but in the treatment of the various drainage areas, in the arrangement and direction of the main lines of sewers, and in other particulars, it is, in our judgment, decidedly inferior to it.

"The most marked feature in the plan of Mr. John Phillips is a deep tunnel from Twickenham to Plumstead Marshes, at a depth of seventy-eight feet beneath the surface, and passing several times under the Thames. It proposes the separation of natural, or land and surface waters, from artificial, that is to say, house and soil drainage. The drainage on each side of the tunnel is effected by a series of branch intercepting sewers, the directions of which have been well considered, and display a thorough knowledge of all the localities they traverse, and the peculiar difficulties to be encountered in each case. It is probable that the system of branching sewers here proposed would be one of the best systems that could be devised for effecting the drainage of London, supposing the Thames to be maintained as an outlet; but the case is wholly altered when this system is viewed in conjunction with a deep tunnel. It is contemplated that the sewage should be pumped from the terminal depôts to an elevated reservoir on Shooter's

Hill, from whence it is to be distributed for the purposes of the agriculturist. The expenses of this scheme would, even if it were unobjectionable in other respects (which it is not), render its execution commercially impracticable. But the exclusion of the surface water from the channels for soil drainage, where it might be advantageously employed, the necessity of providing an extensive system of new sewers, the construction of a costly tunnel without adequate objects, and the bringing down the drainage of the high grounds to the lowest level to be pumped up again to a great altitude by means of complicated and expensive machinery, all of which are incident to this scheme, appear to us valid objections to its adoption. But in expressing this opinion, it is proper to state, that the plan is distinguished by a thorough knowledge of the localities to be dealt with, and by great merit in the drainage details. It furnishes many valuable hints, and cannot fail to be of use in carrying out the system to be eventually adopted.

"The system of Mr. Austin is to concentrate the sewage of given areas at different centres or points, at which engine power is to be applied for forcing it in a liquid state into various agricultural districts adjacent to the Metropolis. The mode of collecting the sewage on the north side of the Thames, is rather by means of intercepting sewers, in conjunction with sumpts; on the south side, it is effected by central sumpts and engines: the specific mode of distributing the sewage is not clearly stated, but some allusion is made to that said to be practised by the existing Sewage Manure Company. He contemplates discharging the sewage into the Thames, when there is no demand for sewage manure. The suggested line of intercepting sewers on the north side, terminating at the river Lea, is a judicious one, as is that between the Effra and Ravensbourne. Many of the views propounded by Mr. Austin are correct in the abstract; but the multiplication of these receptacles for sewage matter in the Metropolis, the entire dependence upon machinery for the efficiency of the system, and the great mechanical difficulties attending the storing of a vast mass of sewage for several months in the year, or discharging it into the Thames, are, amongst others, serious objections to this project.

"Several other schemes evince merit in some portion of their details, and furnish useful hints on incident branches of the subject. The schemes we allude to are those of—

Mr. Allen,	Mr. Dunn,	Capt. Moorsom,
Mr. Bardwell,	Mr. Gibbs,	Mr. Netherway, and
Mr. Doull,	Mr. Moffatt,	Mr. H. Phillips.

"We think it right, before concluding our observations, to advert to the subject of expense; and though we have felt justified in expressing commendation of several of the propositions submitted to us, we are bound to state that, in our opinion, the estimates sent in are, with scarcely an exception, totally inadequate; a circumstance having a most important bearing upon the subject, as, in appreciating any scheme to be eventually decided on, the question of expense is one of the primary elements for consideration. As already remarked, the object of these observations is to present to the minds of the Committee the more prominent characteristics of the plans they are called upon to consider, and not to define the system of drainage, which it may hereafter be considered expedient to adopt.

"(Signed) J. F. Burgoyne.
James Vetch.
J. M. Rendel.
H. D. Harness.
Robert Stephenson.

"1, *Greek Street, Soho, March 8th*, 1850."

II.—Report of Mr. Frank Forster, on the Surrey and Kent Drainage.

"In obedience to instructions which I had the honour to receive from you on the 8th ult., I now proceed to furnish a report and estimate for a complete system of drainage for the Surrey and Kent districts, including extensive alterations in the inclinations of existing sewers.

"Notwithstanding the labour and ingenuity displayed in many of the plans for the drainage of the Metropolis sent in last year—some of which, as you stated in your Report of the 8th of March, dealt ably with the general drainage on the north side of the Thames—I have been, as you are well aware, in laying out the plan of drainage for the south side, able to derive little or no practical assistance from any of them, which is to be accounted for, doubtless, by the necessarily defective data on which they were based, owing to the imperfect nature of the information which it was then in the power of the Commissioners to supply to their various authors; but I feel it my duty to acknowledge in the outset the very valuable assistance I have received from plans and suggestions prepared, after consulting the block plans and subterranean surveys, by a member of your Honourable Commission, who kindly placed them in my hands during the preparation of the plan I have now the honour to submit.

"In drawing up this Report I have, under your instructions, adopted the following principles for my guidance:—

"1. To keep the river Thames free from sewage at all times of the tide from Woolwich Reach upwards.

"2. To abolish all open ditches and cesspools, as well as defective, shallow, or high-level sewers.

"3. To maintain a continual and unintermitting flow, with the aid of lifts where necessary, in all the sewers along their whole length, by which the evils arising from pent-up sewage—viz., the generation of noxious gases, and the unavoidable formation of deposit in the sewer during its stagnation may be avoided.

"4. To construct the sewers at inclinations so proportioned to the volume of fluid to be carried off by each, that the velocity of the current shall keep them clear of deposit without the need of regular periodical flushing, which experience has shown to be not only troublesome and expensive in its operation, but also very injurious to the sewers and drains in which it is practised.

"5. To form the main sewers at such a depth as not only to receive the drainage of the deepest existing sewers, but to answer the purpose of main drains capable of extension towards the extremities of the district.

"6. To provide a natural escape by the power of gravity alone, for storm waters and land floods, independent of the ordinary sewers, whose contents will, on the south side of the Thames, require artificially lifting, and to construct the new sewers of such sizes only as may be sufficient to take the general drainage of the district, including ordinary rainfalls connecting them at about mean low water with outlets for heavy floods.

"7. To follow existing public streets, roads, or paths, so as to avoid heavy compensation for injury to private property whenever this can be done, without causing injurious curves or undue prolongation of the sewers and consequent loss of level.

"8. To extend the ramifications of the sewers after the main lines are completed into all the streets at such depths and with such inclina-

tions as to give perfect self-cleansing street drainage, and the opportunity for efficient house drainage.

"The following is a general outline of the means proposed to effect the objects above named :—

"I beg to recommend the top of Woolwich Reach as the point for delivering the sewage into the river, because I believe that the matter so delivered at and after high water, and in the centre, and at the bottom of the stream, will not rise to the surface, so as to inconvenience the inhabitants of Woolwich. If, however, it should be deemed expedient, either for agricultural purposes or for any other reason, to convey the sewage below Woolwich to some point near Erith before its delivery into the Thames, it may be effected by means of iron pipes across the Marshes and through Woolwich, to be supplied by an engine and standpipe erected at or near the Woolwich Road, near Greenwich Gate.

"Commencing with the outlet at a point eight miles below London Bridge, it is proposed to form a double reservoir capable of holding at least twenty-four hours' drainage, covered over, and elevated to such a height as to discharge the whole of its contents at high water, delivering them by means of pipes near the middle and at the bottom of the river. The sewage will be lifted into the reservoir at this point (by means of an engine) from the main sewer, the invert of which is proposed to be at about mean low water, and 10 feet below the surface of the Marshes.

"From hence the course of the main sewer will be across Greenwich Marshes, along Woolwich Lower Road, Trafalgar Road, and Roan Street, to the Ravensbourne (where there is proposed to be a lift not exceeding 25 feet) passing under the river Ravensbourne past the corner of the Trinity Almshouses, and crossing Union Street and Bridge Row or Collier Street.

"This lift and shaft I propose to place completely under cover, and to connect with the chimney of the smoke-consuming furnace of the engine all the passages from which any gases could escape from the sewer, and I feel perfectly confident that, with these precautions, the possibility of any annoyance being caused to the neighbourhood may be obviated.

"I mentioned above, that it was not proposed that the engines should have to raise all the storm waters or land floods; these will be provided for in extraordinary cases by the four existing outlets, viz., the Effra, the Earl, the Duffield, and St. John sewers, and by means of reservoirs and a diversion of the upper part of the Effra, to keep the low-lying and thickly-inhabited part of the district free from floods.

"From Collier Street, a line, which may be called the 'southern main line,' diverges; the 'northern main line' passing along the Lower Deptford Road to the crossing of the Earl sewer, from which point it strikes into a north-westerly direction, and in a straight line towards St. James's Church, Bermondsey, thence along Prospect Place to Dockhead, and thence to Gainsford Street and Tooley Street, where it unites with the great St. John's sewer, with which are connected the Battle Bridge and its various branches; the inclination of the new sewer for the whole distance being at an average rate of about 4½ feet per mile, somewhat less near the point of discharge, somewhat more, of course, as the volume of fluid diminishes at each successive ramification of the sewers.

"Returning to the diverging point at Deptford, the course of the 'southern main line' will be by Loving Edward's Lane, nearly in a straight line with Old Kent Road at Hatcham, along the Old Kent Road to Surrey Canal Bridge, which is at the point of divergence of an intermediate main line to be afterwards described; the southern main line will proceed by Neat Street and Albany Road in a straight line across to St. Mark's Road, and by Camberwell New Road to St. Mark's Church, Kennington. Here it will pass under the Effra sewer, and, by a connection therewith, will receive its ordinary run of drainage;

the floods of the Effra being provided for by a relief line about 1,200 yards long, passing along the Oval and Harleyford Street to Vauxhall Creek, the present open and most offensive portion of the Effra from Kennington Road to Vauxhall being filled up and abolished.

"The level of the southern main line at St. Mark's Church would be about 1·0, or nearly 7 feet below the deepest sewer existing there at present, and will afford unexceptionable drainage for Stockwell and Clapham, Balham Hill, and the whole district lying between the Brixton Road and Wandsworth Road.

"The course of the 'intermediate line,' diverging at the Surrey Canal Bridge, proceeds along the Old Kent Road to the Bricklayers' Arms, where it will divide: one arm passes along the New Kent Road to the Elephant and Castle, where it will receive the drainage of the Walworth and Kennington Roads and a portion of London Road and St. George's Road.

"The other more northern arm of this intermediate sewer proceeds from the Bricklayers' Arms along part of the Dover Road and Trinity Street, crosses Blackman Street, continuing along Great Suffolk Street, across Southwark Bridge Road, along Suffolk Street, across the end of Gravel Lane, through Nelson Square, to Rowland Hill's Chapel, at which point its level will be 0·40, being about 1 foot 2 inches below the Battle Bridge Sewer. This intermediate main line will be 2¼ miles in length from the Surrey Canal Bridge to Rowland Hill's Chapel—one-half of it through streets at present without deep sewers, and one-half along the line of an existing deep sewer, for which it will form a substitute, and the more southern arm passing up to and dividing at the Elephant and Castle, about 1 mile in length, along the lines of existing sewers. The inclinations of the proposed new lines varying at the different parts of the sewer according to the branches received on the principle above mentioned.

"Consequent upon this intermediate main line being carried into the middle of the populous district will be an alteration of the levels of above six miles of existing sewers in the following streets, viz., New Cut, Cornwall Road, Waterloo Road, Borough Road, Newington Causeway, Westminster Bridge Road, Lambeth Road, Westminster Road, parts of London Road, and St. George's Road. This will involve in addition much alteration in secondary drains and in house drainage; and I cannot quit this part of the subject without again suggesting to the Commissioners the expediency of watching and testing the working of the present main drains, as soon as the main sewers are sufficiently completed to do so, before they proceed to the extensive alterations in the existing sewers which the contemplated interference with them will involve.

"I beg now to lay before you my estimate of the cost of draining the district according to the system above described; but before doing this I would observe that in drawing up this report and these estimates, I have thought it desirable to put down the outside amount of lift, of depth of drains, &c., in order if there be any error it may be on the right side. In this estimate I have neither included compensation for passing through or under private property, which, however, from the lines adopted in accordance with the principle you laid down, will be comparatively trifling, nor the cost of the detailed drainage, to estimate which will be a work of much time and lengthened inquiry. In any case this will involve a considerable outlay, but as it is dependent on the settlement and partial completion of the main drainage, it would have been premature to go into it here; neither have I taken into account the cost of extending the system of drainage into the suburban districts—a provision which it becomes daily more imperative to make.

"*Estimate of Cost of system above described.*

	Miles.	Fur.		Cost.
Main trunk drain from outlet in Greenwich Marshes to the lift at the Ravensbourne	2	0	..	£25,887
Reservoirs and outlet pipes				20,280
Pumping engines and apparatus				27,400
From the lift at the Ravensbourne to a point near St. James' Church, Bermondsey, north main line	2	5	..	46,930
Extension of north main line from St. James' Church to the Great St. John Sewer	0	6	..	8,000
South main line from Collier Street, Deptford, to St. Mark's Church, Kennington	4	0½	..	49,600
Flood line of Effra	0	5½	..	7,200
Intermediate main line from Surrey Canal Bridge, with northern arm to Rowland Hill's Chapel	2	2	..	12,000
Southern arm along New Kent Road	1	0	..	5,000
Alteration of existing sewers to connect with the intermediate main line, &c. . . . . 6 m. 0 fur.			..	32,000
Effra flood line diversion by Peckham				7,000
	13	3		£241,297

"(Signed) FRANK FORSTER.

"1, *Greek Street, Soho, August* 1, 1850."

III.—REPORT OF MR. FRANK FORSTER ON THE DRAINAGE OF THE DISTRICTS NORTH OF THE RIVER THAMES.

"I have the honour, in accordance with instructions received from you on the subject of the drainage of the northern part of the Metropolis (which instructions are transcribed below), to lay before you my Report.

COPY OF INSTRUCTIONS.

"'Resolved, That in effecting the drainage of this portion (northern) of the Metropolis, it is expedient—

To keep the river Thames, within the Metropolitan districts, free from sewage at all times of the tide.

To provide an escape by means of intercepting drains for so much of the sewage of the north side of the Thames as admits of being so carried off.

To raise all other sewage by artificial means, so as to deliver into a main channel for removal, in accordance with the foregoing resolution.

So to construct the intercepting sewers as to secure the largest amount of effective drainage without having recourse to artificial means.'

"'Resolved, That the fall of the main intercepting sewer from Albion Street, Uxbridge Road, into the river be in no place less than 4 feet per mile.'

"'Resolved, That Mr. Forster be directed to prepare plans and estimates, according to the foregoing resolutions, carrying the whole of the sewage to Gallion's Reach, at the same time considering the alternative, in the event of accident to such machinery as may be necessarily employed to carry the same into or near the river Lea.'

"'Resolved, That the Engineer be instructed to prepare by Friday next, the 31st instant, a full and detailed report, with plans and sections, in accordance with the resolutions of the Committee on the drainage of the whole of the Metropolis north of the Thames, including the City of London, and that he avail himself of the assistance of Mr. Haywood in such duty.'

"In conformity with this resolution, I have now the honour to lay before you my Report, which will be found to agree with the conclusions arrived at on the points reported upon by Mr. Bunning, Mr. Haywood, and myself, and approved of by your Honourable Commission. I beg to add, that in the numerous calculations and other considerations requisite in drawing up this Report, I have had the benefit of Mr. Haywood's advice and assistance throughout.

"In devising a plan of drainage for the northern portion of the Metropolis, in accordance with the instructions before stated, and also in conformity with those principles by which I was guided in laying down the plan for the interception of the sewage of the southern side of the Thames,—the district appears to divide itself into two separate areas, for which different means require to be adopted, viz.:—

1. The interception of the drainage of that district, which, from its elevation above the level of the outlet, is capable of having its sewage and rainfall carried off by gravitation.
2. The interception of the drainage of that district, which, from its low lying position, will require its sewage, and in most localities its rainfall, to be lifted by steam power to a proper level for discharge.

"These two districts are indicated upon the general Map attached hereto by distinctive colours.

"The district for natural drainage is tinted red, its area being about $25\frac{1}{6}$ square miles.

"The district for artificial drainage is tinted blue, its area being about $16\frac{1}{6}$ square miles.

"In the two small tracts coloured dark blue, viz., the southern part of the Isle of Dogs, and a narrow tract on the west side of the river Lea, it is intended to allow the rainfall to run into the Thames and the Lea respectively; the area of these two tracts amounts together to $1\frac{3}{4}$ square miles.

	Rainfall. Square Miles.	Sewage. Square Miles.
The total area, therefore, proposed to be drained by natural outfall from the district coloured red, will be about	$25\frac{1}{6}$	$25\frac{1}{6}$
The total area proposed to be drained by the application of steam power from the district coloured blue, will be about	$14\frac{1}{3}$	$16\frac{1}{6}$
The total area being about	$39\frac{1}{2}$	$41\frac{1}{3}$

"It will be observed, that the district lying to the south-west of the portions tinted red and blue upon the general Plan, is not included in the foregoing calculations of areas, although it contains a portion of the Counter's Creek and the Fulham and Hammersmith Districts, the total area of which is about sixteen square miles; of this area but a very small portion is at present built upon; and probably if one half, or eight square miles, is estimated as requiring the provision of means for the interception of its sewage and rainfall, it will include an area which may not be built upon and populated for the next half century; I have not, therefore, deemed it needful to provide in

my Plan for the interception of the sewage and rainfall of a larger area than eight square miles.

"An additional reason for not doing so is, that the establishment of the Metropolitan Sewage Manure Company's Works is in the heart of the district, which is eminently adapted for the application of sewage water as a manure, and affords grounds for belief that the whole of the sewage produced in the district may be profitably applied, and that the interception of the *sewage*, even of the eight square miles, may not be rendered necessary, although, to guard against contingencies, I have provided for that area in calculating the sizes of the main low level line.

"In the event, therefore, of the sewage not being applied as expected, it may be lifted and discharged with the rest of the northern sewage at Barking Creek; but it will be needful in that case to extend the Whitehall Sewer from Scotland Yard, so as to intercept the main low level sewer at Chelsea Road.

"Having described the tracts to be drained, I have now to lay before the Committee a statement of the means by which it is proposed to accomplish the effectual interception of sewage upon the principles laid down.

"Commencing with the upper portion of the tract coloured *red* upon the general Plan, and taking as a starting-point the Pumping Station (hereafter to be more fully alluded to) on the eastern bank of the river Lea, at which point the whole of the sewage of both the high and low level districts will be concentrated, the main high-level sewer commences and crosses over the river Lea, near the 'Four Mills,' proceeding in a westerly direction under the East and West India Dock Railway, and the Blackwall Extension Railway, beneath the Regent's Canal, to the east end of the Bethnal Green Road, at the crossing of the Cambridge Heath Road, at which point it will be joined by the proposed northern diversion of the Hackney Brook, which drains an extensive district up to the water shed line north of London, including Hackney, Stoke Newington, and Holloway, and part of Highgate and Hampstead; from thence the main sewer proceeds along the Bethnal Green Road, Church Street, Old Street, Wilderness Row (where a short branch from Coppice Row will join) to Brook Street Hill, from thence to Little Saffron Hill, where a distance of about 100 yards is proposed to be carried by an aqueduct over the Fleet Valley, thence along Liquorpond Street, at the end of which it will receive a branch from Piccadilly on the south side, and a diversion of the Fleet River on the north side, thence along Theobald's Road, Bloomsbury Square, Hart Street, New Oxford Street to Rathbone Place (where it receives a diversion of the Regent Street Sewer from Park Crescent), along Oxford Street, and extending thence across Regent Circus to South Molton Lane (where it will intercept the King's Scholars Pond Sewer), continuing still along Oxford Street to Grand Junction Road, Uxbridge Road, where it is joined by the Ranelagh Sewer, the sewage of which it is capable of receiving, and at this point it terminates.

	Miles.	Yds.
The length of this main high-level sewer will be about . .	7	1,143
The Hackney Brook Branch, North	6	1,417
The Coppice Row Branch, North	0	1,135
The Piccadilly Branch, South	1	1,585
The interception of the Fleet up the Gray's Inn Road, North	1	266
The Rathbone Place and Cleveland Street interception of the Regent Street Sewer, North	0	1,600
Making a total of . . .	19	106

"With respect to the low-level tract coloured blue on the general Plan, it is proposed (commencing as before at the lifting point on the eastern bank of the river Lea) to construct a sewer at a depth of 47 feet below the invert of the

high-level sewer, proceeding beneath the river Lea, near to Four Mills Distillery, taking the north-western bank of the Limehouse Cut, at which point it receives the branch intended to intercept the sewage of the Isle of Dogs; thence continuing along the bank of Limehouse Cut through a portion of the Commercial Road, Brook Street, and beneath the Sun Tavern Fields into High Street or Upper Shadwell, at a point opposite to the church; thence along Ratcliff Highway and Upper East Smithfield, across Tower Hill through Little and Great Tower Streets, Eastcheap, Cannon Street, Little and Great Saint Thomas Apostle, Trinity Lane, Old Fish Street, and Little Knight Rider Street; thence beneath houses in Wardrobe Terrace, and on the eastern side of Saint Andrew's Hill along Earl Street to Blackfriars Bridge. From Blackfriars Bridge it is proposed to construct the sewer along the river shore to the junction of the Victoria Street Sewer at Percy Wharf; which sewer between Percy Wharf and Shaftesbury Terrace, Pimlico, becomes thus an integral portion of the intercepting line; at Bridge Street, Westminster, a branch from the Victoria Street Sewer is intended to proceed along Abingdon Street and Millbank Street, as far as and for the purpose of taking up the King's Scholars Pond and other sewers at their outlets into the Thames.

"From Shaftesbury Terrace the Victoria Street Sewer is proposed to be extended through Eaton Square and along the King's Road, Chelsea, to Park Walk, intercepting all the sewers along its line, and terminating at a point where the drainage of Kensington may be brought into it without pumping.

	Miles.	Yds.
The total length of the main low-level sewer, including the extension of the Victoria Street Sewer to Chelsea, will be about	8	1,601
The length of the branch southwards and westwards for the drainage of the Isle of Dogs, about . . .	4	360
The branch from Bridge Street, Westminster, along Millbank	1	1,300
The total length being about . .	14	1,501

"Having now described the whole of the lines of intercepting sewers, westward of the proposed pumping station on the eastern bank of the river Lea, I have in the next place to lay before you a similar statement as regards their proposed extension from that point to the outlet.

"The invert of the high-level sewer at the pumping station will be 20 feet above the Ordnance datum; the invert of the lower level sewer will be 27 feet below the Ordnance datum: the difference between the two being about 47 feet; the sewage of the lower level will thus be lifted to the higher level by steam power, and both will be conveyed by two parallel lines of sewers from the pumping station to the bank of the river Roding, being the eastern extremity of Gallion's Reach. The length of this extension will be four miles.

"At this point the level of the inverts of the parallel sewers will be 8 feet below high-water mark; and here it is intended to collect the sewage into a reservoir during the flood tide, and discharge the same with the ebb tide immediately after high water; and as it is estimated that the reservoir will be completely emptied during the first three hours of the ebb, it may be safely anticipated that no portion of the sewage will be returned, with the flood tide, to within the bounds of the Metropolis.

"The inclination which has been assigned to the whole of the lines of sewers, with the exception of an inconsiderable portion, is not less than four feet per mile, or 1 in 1,320.

"The sewers are calculated to carry off a fall of rain equal to a quarter of

an inch in twenty-four hours, in addition to the average daily flow of sewage, which in anticipation of the progressive increase in the population, has been assumed at double the present water supply.

"The pumping power needed to raise the sewage and rainfall of the lower level to the required height (or 47 feet), is estimated at 1,100 horses power, in order to meet which it is proposed to erect two 550-horse power engines, together with a third engine of equal power (550-horse power), to meet the contingency of accident, or want of reparation.

An abstract of the various lengths of sewers proposed will be as follows, viz. :—

	Miles.	Yds.
Of the high-level sewer and its branches	19	106
The low-level ditto and branches	14	1,501
The extension from the Pumping Station to the point of discharge at Barking Creek (parallel sewers) 4 miles in length	4	0
Making a total of	37	1,607

"The whole of the sewage and rainfall, with the trifling exception before stated, of the areas coloured red and blue upon the plan (which at present discharge by the various outlets into the Thames) will be diverted and carried down to Barking Creek, excepting upon the occurrence of long continued and heavy rains, or unfrequent and violent storms, when the surplus water will be carried off by certain of the existing outlets into the river, but upon all such occasions the first scour or cleansings of the sewers will be conveyed to the main outlet at the river Roding.

"From the time consumed in the manifold considerations, necessarily involved in works so extensive in their nature, I have been prevented from laying before you a detailed estimate of the cost of the plan of interception. I am, therefore, only able to submit approximately, that I estimate the cost of the whole of the lines of sewers, the pumping engines, and station, the reservoir, tidal gates, and other apparatus, at one million and eighty thousand pounds (£1,080,000).

"This estimate does not include the sums required for the purchase of land and houses, which may be needed for the site of the pumping engine-house, and compensation for certain portions of the lines of sewer.

"(Signed) FRANK FORSTER.

"*London, January 30th*, 1851."

MEMOIRS.

Mr. THOMAS BARTLETT was born on the 7th of July, 1818. His professional career commenced under Mr. John Wright (M. Inst. C.E.), to whose kindness he always acknowledged himself indebted, and under him he was engaged during the execution of a portion of the South Eastern Railway, where he took an active part in the proceedings for blowing down the face of the Round-Down Cliff, near Dover, and he there attracted the notice of Mr. (afterwards Sir) W. Cubitt, Past-President, the Engineer-in-chief of the line. He then had charge of the construction of the portion of the Great Northern Railway from London to the tunnel at South Mimms, and the cutting beyond towards Welling, for Mr. Brassey (Assoc. Inst. C.E.), the contractor for the works, under Mr. Joseph Cubitt, V.P. Inst. C.E. On the completion of the Great Northern line, Mr. Bartlett became permanently attached to Mr. Brassey's undertakings, and was intrusted with the construction of the Victor Emmanuel Railway, the highway between France and Italy, where he executed some extensive works with great skill and success. He was afterwards engaged in the execution of the works on the Bilboa Railway, Spain, designed by Mr. Vignoles (M. Inst. C.E.), having an interest in the contract with Mr. Brassey and the late Sir Joseph Paxton, M.P. (Assoc. Inst. C.E.). These works— which are remarkable for the natural difficulties presented by the mountainous country through which the line passes—were executed with great skill and perseverance, under the depressing influence of inevitable loss, and in the prosecution of them the pecuniary means of Mr. Bartlett suffered severely. Nothing daunted, however, by his ill fortune, he energetically set to work again to retrieve, if possible, his position, and he returned to Portugal, where he was seized with rheumatic fever, brought on by undue exposure, and he expired at Lisbon in the 46th year of his age, on the 23rd of July, 1864, only a few hours after receiving the news of the decease of his wife, whose death preceded his own by less than a week, leaving a young family of seven children unprovided for. This melancholy termination of the career of a highly-respected Member of the profession, painful as it was, has had a tacit but powerful influence in the formation of 'The Benevolent Fund of the Institution of Civil Engineers,' which, under good management, is

destined to be of great benefit to the unfortunate members of a profession peculiarly exposed to vicissitude.

Mr. Bartlett was well grounded in the theory and practice of his profession; had considerable experience, and possessed the power of managing large bodies of workmen—a peculiar and very valuable talent—due in a great measure to his cheerful and genial disposition, inspiring confidence in all those with whom he came in contact. He was fertile in resources, and in foreign countries he always knew how to engraft upon the ordinary proceedings of the indigenous labourer, only as much of the English system as would facilitate the execution of the work, without interfering with the prejudices of the people. He was an ingenious mechanic, and among other inventions, he was the original projector of an automatic-tunnel boring machine,[1] analogous in principle to, but preceding in date, that which is now so extensively employed in the Mont Cenis Tunnel, under the intelligent direction of Monsieur Sommeillier, one of the patentees of the condensed air-boring machine.

Mr. Bartlett joined the Institution of Civil Engineers as an Associate, June 24, 1845, and was transferred to the class of Members November 16, 1852. He was precluded, by his prolonged residence abroad, from being a frequent attendant at the Meetings; but whenever he was in London he made a point of taking part in the proceedings, which he did with good effect, from the practical knowledge he displayed respecting all the subjects upon which he spoke.

The melancholy circumstances of his decease, and his own intrinsic merit, will cause him to be long remembered and regretted among the members of the profession.

Mr. THOMAS CASEBOURNE was born in 1797 at Hemel Hempstead, Herts. In early life he devoted himself to engineering pursuits, and was a favourite pupil of Mr. Telford, by whom he was employed as assistant on several works, and subsequently, amongst other duties, he was engaged in drainage works in the Lincolnshire Fens, on the London and Liverpool Road, the Metropolitan Water Survey, &c. From 1833, and for twelve years subsequently, he had charge of the execution of the works of the Ulster Canal, which were originally designed by Mr. Telford, and were subsequently under the direction of Mr. (afterwards Sir W.) Cubitt (Past-President). This canal was designed to facilitate the intercourse between the west and the north of Ireland, by effecting a junction between Lough Neagh and Lough Erne. A description

[1] *Vide* Minutes of Proceedings Inst. C.E. vol. xxiii.

of a portion of these works, accompanied by drawings, was presented to the Institution of Civil Engineers in the Session 1842,[1] and for it Mr. Casebourne received a Telford Premium of Books.[2] In 1845 he removed to the locality now so well known as West Hartlepool—then a mere hamlet—to undertake the Resident Engineership of the Harbour and Docks constructed there; and since that period his name has been intimately connected with all that related to the port, harbour, and town of West Hartlepool. In 1850 he submitted to the Institution a Paper[3] descriptive of a float, or fixed platform, which he had used for submarine blasting in the bay of Hartlepool, and which was stated to have answered its purpose extremely well. On the incorporation of the Commissioners of West Hartlepool in 1854, he was one of the original Commissioners appointed under the Towns Improvement Act; and he continued to fill the office of Commissioner up to the period of his decease. He was for some time Chairman of the Board, only resigning that appointment in favour of Mr. R. W. Jackson (Assoc. Inst. C.E.) a week or two before his death. He also for a short time represented the West Hartlepool town interest in the Pier and Port Commission; but on the resuscitation of the Refuge Harbour question, he retired from that office, in order that he might not sit in judgment upon his own, amongst other competing plans. At the West Hartlepool Improvement Board, Mr. Casebourne was a regular attendant. He was also for many years a Vice-President and Life Member of the Local Literary and Mechanics' Institute.

Mr. Casebourne was elected an Associate of the Institution of Civil Engineers on the 12th of February, 1828, and was transferred to the class of Members on the 26th December, 1837. His decease occurred on the 2nd of January, 1864, in the sixty-sixth year of his age. He was a careful, conscientious man, had a good knowledge of the practice of Civil Engineering, and very deservedly, acquired the confidence of all with whom he was brought into contact.

Mr. JOSEPH GIBBS was the youngest son of a mill-owner and manufacturer in Staffordshire, where he was born in the year 1798. His uncle was mineral agent to the Duke of Devonshire, and among the mines of the Derbyshire hills Mr. Gibbs first acquired a taste for engineering operations and geological research. He then visited Holland, and was engaged to superintend some hydraulic works in the Dutch colonies; and he resided for some time at Demerara, Berbice, and other places in the West Indies. On his return to England he associated himself with an excellent

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. ii. (1842), p. 52.
[2] *Ibid.*, vol. ii. (1843), p. 6. [3] *Ibid.*, vol. x., p. 293.

and ingenious mechanic, Mr. Smart, of Lambeth, and while with him, he superintended the erection of several extensive corn and saw mills in the neighbourhood of London. He soon after completed and patented a series of inventions for sawing and cutting wood, metal, and stone ; and he established some extensive works at Crayford Mills, in Kent, and also in London for their development. Among the various mechanical inventions contained in these patents was that now well-known and used, called in Holtzapffel's work, " Gibbs' elbow joint." This invention is now applied in many ways in the construction of machine tools and other mechanical contrivances ; it consists in giving to a cutting point revolving at a high velocity, the capability of being conducted in every direction, and any pattern can thus be engraved in copper plates, and statues in marble, in relief, and the round can thus be copied with mathematical accuracy. The chief purpose to which this series of ingenious inventions was applied practically, was to the construction of inlaid floors. At Buckingham Palace, at Apsley House, at Windsor Castle, at the Duke of Northumberland's residence, Sion House, and other places, floors were laid down composed of an infinite number of pieces of wood of every kind and shape, forming the most elaborate designs, each piece being cut out and made accurately to fit its fellow, and to be secured with a tongue, by this machinery ; the surfacing and polishing only being done by hand. These floors are now in precisely the same state as when they were first laid.

For many years Mr. Gibbs was engaged in erecting machinery, &c., in England, Ireland, and Holland, for manufacturing purposes, and for lifting water. Having commenced his career in a Dutch colony, and associated with Dutch Engineers, his attention was early turned to the best method of draining the great lake called the Harlemmeer Meer ; but some time elapsed before he could persuade the Dutch authorities that steam power was better than wind for the purpose of draining this inland sea. Eventually the Dutch Commissioners, after visiting the great pumping establishments of this country, arrived at the conclusion that Mr. Gibbs's views were correct ; and he and his partner, Mr. Arthur Deane, were commissioned by the Dutch Government to execute the work. Engines of a novel and ingenious kind, specially adapted for the peculiarities of the undertaking, were constructed at the Hayle Foundry, Cornwall ; and ingeniously overcoming great difficulties, the whole of the water of the Meer was lifted within the time stipulated. Commercially this work was a great success ; the country was congratulated, and the Commissioners and Engineers were complimented in a speech from the throne, and the site of the Harlemmeer Meer is now one of the most fruitful and best cultivated portions of Holland.

Having constructed some mineral railways, and attempted on an extensive scale the scheme of running carriages, propelled by steam, on common roads, Mr. Gibbs turned his attention to the construction of passenger railways; among his first designs were the present Great Northern Railway, and a line from London to Brighton; for the first portion of the latter, as far as Croydon, his Company obtained a Bill, and he constructed the present line to that place. He had surveyed one of the numerous competing lines to Brighton, but, after a severe parliamentary contest, the present line was adopted on the advice of Colonel Alderson. In order to avoid an expensive opposition before the Committees of the House, the Croydon Railway Company purchased the old Croydon Canal; and in the endeavours to use the land so obtained, great difficulties of locality were encountered, and a uselessly steep incline was surmounted, which might have been avoided by following the evident course of the Ravensbourne. The Bill for the Great Northern Railway was thrown out on the second reading; some years later, Mr. Gibbs re-surveyed the line, but he was again unsuccessful. In 1844 the scheme was again brought forward, as the London and York Railway; eventually a Bill was obtained for it in a modified form, under that title, and was afterwards changed to the present, the original title of 1836.

Mr. Gibbs gave evidence before Parliamentary Committees upon nearly all important scientific inquiries, and he generally published his opinion upon them *in extenso*. He is also the author of an excellent book on the "Cultivation of Cotton." He was during his life a great traveller, having visited nearly all the countries of Europe, Asia Minor, Egypt, the East and West Indies, Australia, and New Zealand. He made several interesting geological and other surveys, and throughout his professional career he took great interest in the manufacturing arts, with the theory and practice of which he was well acquainted, especially in reference to textile fibres, many processes and machines invented by him being now in use. He had a high appreciation of the beauties of Nature, and he was so good an artist, that had not his predilections been for engineering, he would probably have practised the art of painting as a profession. He joined the Institution of Civil Engineers, as a Member, on the 6th April, 1852, and was a frequent attendant at the Meetings, taking a prominent and useful part in the discussions, when the expression of his opinions and the results of his practical experience, were always received with great respect by all the leading Members of the profession, by whom he was regarded with feelings of esteem and confidence. He was a warm hearted, kindly man, believing and trusting everybody, of unbounded generosity, which was too often imposed upon, to the ultimate injury of his own circumstances, and the prospects of his

family. His decease, after a long and painful illness, occurred on the 11th February, 1864, in the sixty-sixth year of his age; and his memory will long live among all those Members of the profession who came in contact with him.

MR. GEORGE HURWOOD was the son of Mr. William Hurwood, a millwright resident at Bullingdon, near Sudbury. At an early age he was apprenticed to his uncle, Mr. Samuel Wright, a millwright having extensive practice at Ipswich, under whose tuition he became a very skilful workman, and was employed on some of the most important works in the district. He was so devoted to the mechanical art, that the chief portions of his leisure hours were occupied in constructing models of machines of great accuracy and beauty, one of which—that of a steam-engine—held for some years a prominent position at the Polytechnic Institution, London. In due time his recognized skill and industry had their reward, and in 1837 he was established at Ipswich, by some gentlemen of capital, in a foundry, as managing partner of the firm of Bond, Turner, and Hurwood, where there were constructed some good steam-engines, and the machinery for many corn and paper mills, &c.

At the period of the construction of the Ipswich Docks, he took much interest in the progress of the work, and was entrusted with the contract for the dock-gates, which he executed very satisfactorily. About the year 1850 his connection with the foundry ceased, and he established himself as a Consulting Engineer at Ipswich, and eventually he became, on the resignation of Mr. James Jones, the Resident Engineer of the Docks at that place, which post he held with great credit to himself and advantage to the port, until his decease, which occurred on the 26th of February, 1864.

He was at one period frequently employed by the Admiralty to conduct investigations on the probable effect upon tidal waters of projected railway and other works, and his judgment was highly respected.

He invented and patented several ingenious and useful mechanical contrivances, which have been extensively employed. He joined the Institution of Civil Engineers as an Associate April 5th, 1842, and was transferred to the class of Members February 27th, 1854. He was a frequent attendant at the Meetings, taking a useful part in the discussions, and he contributed two Papers entitled respectively "Description of a plan adopted for carrying off an Accumulation of Water, from the Warehouses, Cellars, &c. near the Wet Dock at Ipswich,"[1] and "On the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. ii. (1843), p. 183.

River Orwell and the Port of Ipswich,"[1] for the latter of which he received a Council Premium of books, Session 1860-61.

Mr. Hurwood was a quiet unobtrusive man; he was not only a skilful mechanic and a good Engineer, but he possessed clear judgment, and he had by study and extensive reading well stored his mind. He was highly respected by his employers and by his fellow townsmen, by whom he was much regretted as a useful member of society.

Mr. JAMES JONES was born in London April 6th, 1790, and was, during the early part of his career, in business as a copper and tin worker, having an establishment near the London Docks, the engineering department of which was at that time under the direction of Mr. Telford, as Engineer-in-chief, represented by the late Mr. H. R. Palmer, V. P., by whom he was employed to execute some models of machines. These were completed in such a satisfactory manner as to induce a considerable intimacy between the two, then, young men, and led to Mr. Jones being eventually offered a position under Mr. Palmer, whose principal assistant he ultimately became; assisting him in several ingenious inventions, particularly in the introduction of corrugated iron, for which Mr. Palmer took out a patent. He also became the contractor for the maintenance of the machinery at the Docks, which he continued for a considerable period, only leaving that position to take the appointment, in 1831, of 'Resident Mechanist and Engineer' at the St. Katherine's Docks, for which he was highly recommended by Mr. Telford and Mr. Palmer, and which he held until the year 1836.

When Mr. Palmer undertook, in 1838-39, the construction of the dock at Ipswich, Mr. Jones was appointed the chief Assistant-Engineer, and he executed all the details with such skill and ingenuity, that on the completion of the works, in 1842, he was appointed manager of a part of the engineering establishment of Messrs. Ransomes and Co., of Ipswich, and he held that post until the year 1852, rendering efficient aid in developing the process of manufacturing compressed wood fastenings for railways, patented by the late Mr. Charles May (M. Inst. C.E.), a member of the firm, as also in the ordinary proceedings of the engine-building department of the works. The details of the construction of the Altazimuth instrument, designed in 1845 by the Astronomer Royal, were also mainly under his charge.

In 1852-53, Mr. Jones quitted Ipswich for the appointment of Engineer of the Oxford Waterworks, with which he combined other duties in connection with the local improvements of that city, a

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xx., p. 4.

position which he held with great credit until the year 1864, when he lost his life by a melancholy accident. He had gone to the brewery of Mr. Evans, Cowley Road, Oxford, on the afternoon of Tuesday, the 24th April, 1864, to give some instructions relative to the water-pipes, when, whilst walking on a stage above the vats, he stepped aside to allow one of the workmen to pass, and fell into a vat of boiling liquid; he was speedily rescued from the dreadful position, and was removed to the Radcliffe Infirmary, where, in spite of the skilful attention of the medical officers, he was released from his severe sufferings early in the morning of Wednesday, the 25th April, 1864, in the 74th year of his age. At the investigation into the cause of the accident, very high testimony was borne by the authorities of the city of Oxford as to the value of the services rendered by Mr. Jones, and to the general estimation in which he was held by all who knew him. He possessed more than a common share of ingenuity and experience as a mechanic, and his memory was so tenacious that he was a walking encyclopædia of inventions and experiments. He was a strictly conscientious man; industrious, careful, and upright in all his dealings; and in his position few men have laboured more strenuously and consistently for the benefit of the profession to which he was devotedly attached.

About the year 1817, James Jones was taken into the counsels of Henry Robinson Palmer and Joshua Field, relative to the formation of a small mutual improvement society, to be composed of a few young Engineers. To them were soon added William Maudslay, Charles Collinge, and James Ashwell, and the first meetings were held in a small room in the Strand, James Jones acting as secretary and treasurer, to which combined posts he was formally elected on the 6th of January, 1818, the six founders of the Society having previously constituted themselves Members on the 2nd of that month. Thus was established the Institution of Civil Engineers, speedily countenanced by Telford; and, by the energy of its founders, supported, under many difficulties, until it obtained a Royal Charter, and eventually attained its present important position in the scientific world. It may be imagined with what pleasure Mr. James Jones watched the progress of a Society, to the formation of which he had contributed such efficient aid, and that this feeling was reciprocated by the Members, was shown by the unanimous resolution of the Council to erect a tablet to the memory of their first Treasurer and Honorary Secretary.

Mr. EDWARD OLIVER MANBY, the fourth son of the late Mr. Aaron Manby (M. Inst. C.E.), was born at Horseley,

Tipton, on the 17th of June, 1816. At the age of four years he went to France with his father's family, and received his education at the Collège Massin, Paris, completing it at the University of Ghent, Belgium, where at the early age of sixteen he took high mathematical honours at the examination. He was then sent to England, and became the pupil of his elder brother, Mr. Charles Manby (M. Inst. C.E.), by whom he was eventually placed in the Ebbw Vale Iron Works, at that time the property of Messrs. Harford, Davis, and Co. He there acquired a very good practical knowledge of iron making, in which he was greatly assisted by his chemical acquirements. At that time attention was directed to the introduction of anthracite as a fuel for smelting, and Mr. Crane, of Ynischedwyn, near Swansea, engaged the services of Mr. E. O. Manby for the construction of the furnaces, and for the preliminary investigations and experiments, which were very successful. This made him so well known in that part of South Wales, that he was induced to establish himself as an Engineer at Swansea, where he was joined by his elder brother, Mr. John Manby. Eventually they removed to London, and being employed on several investigations on the Continent, the brothers established themselves at Madrid, where they engaged largely in railways, irrigation canals, gas-works, iron-works, mines, &c., and for many years Mr. E. O. Manby pursued a very active professional career.

His health eventually broke down, and after a long and distressing illness, he died at Paris on the 21st of February, 1864, at the age of forty-eight years.

His talents were of a very high order; he was a fine, generous, high-spirited man, always pleased to do a kindness to any one, and ever careless of his individual interest. He was beloved by all who knew him, any faults he had were of the head and not of the heart, and few persons were more sincerely regretted by those who knew and duly appreciated him.

He joined the Institution of Civil Engineers as an Associate February 25th, 1840, was transferred to the class of Graduates January 19th, 1841, and to the rank of Member April 21st, 1846. In consequence of his almost constant residence on the Continent, he was not able to be a frequent attendant at the meetings, but he always took a strong interest in the proceedings, and he frequently aided other Members by giving them information on foreign works, which enabled some useful Papers to be contributed to the Institution.

Mr. GEORGE MACKAY MILLER was born at Pentonville, on the 7th of December, 1813. After the usual course of school education, followed by attendance for a short time in the mathe-

matical classes at University College, London, he was apprenticed to Messrs. Lloyd, of Southwark, Mechanical Engineers and Millwrights, then in extensive employment. By assiduously working at the bench during the same hours as the men, and subsequently being for a time in the drawing office, he became a sound mechanic. On the death of the acting partner in Messrs. Lloyd's firm, the business was brought to a close, and Mr. Miller, only a few months before the expiration of his apprenticeship, was engaged by Mr. Dixon, then Resident Engineer of the Manchester end of the Liverpool and Manchester Railway, as assistant in his drawing office. Shortly afterwards, he was appointed by the late Mr. Robert Stephenson (Past-President, Inst. C.E.) to perform similar duties in the office at St. John's Wood, where he was employed in making working drawings for the completion of the (then) London and Birmingham Railway. On one occasion, having to go to Birmingham, he left London on an engine which was despatched to test the then recently laid road to a point about midway on the line. Arrived there he, to his great satisfaction, found that another engine had been sent from the other end for the same purpose; and Mr. Miller, alone, exchanged from one engine to the other, so that he always believed himself to have been the first person who ever went direct from London to the Midland Metropolis by steam. Subsequently he became the Resident and Locomotive Engineer of the London and Greenwich Railway, and for some years had charge of that short line, and he there displayed great skill in developing the traffic under circumstances of considerable difficulty. That appointment he resigned, on being selected by the late Mr. Locke, M.P. (Past-President, Inst. C.E.) for the post of Engineer to the Jamaica Railway; a work of much difficulty, both on account of the inaptness of native labour, and the remoteness of requisite material. Mr. Locke was the Consulting Engineer to the Company; but he had such confidence in Mr. Miller, that the latter was intrusted with the preparation of all the drawings, as well as the execution of the work. On his return from Jamaica, after completing the line, he found his health somewhat impaired; but he nevertheless accepted an engagement on the Great Southern and Western Railway of Ireland, as Resident Engineer, combined with the duties of Locomotive Engineer and Superintendent of Rolling Stock of the line. In this situation he remained until his death, and for seventeen years discharged its arduous duties with equal ability and diligence. Mr. Miller caught cold whilst riding on an inclement day in the fulfilment of duty, on an engine, and after a very short illness he died on the 4th of January, 1864, at the age of fifty, in the full vigour of life and usefulness, and to the deep regret of all who knew him.

Mr. Miller was elected a Member of the Institution of Civil Engineers in June, 1844, after he had held the position of Resident Engineer of the London and Greenwich line for upwards of five years, and when about to proceed to Jamaica. When in London, he was a frequent visitor at the Institution, which he always regarded with great interest, and among the Members of which he deservedly had many warm and attached friends.

Mr. RICHARD ROBERTS was born at Carrighova, in the parish of Llan-y-Mynech, North Wales, on the 22nd of April, 1789. The circumstances of his father, who was by trade a shoemaker—with which he combined the post of keeper of the "New Bridge" toll-gate of the Oswestry and Welshpool Tramway—were not such as to enable him to afford other than the smallest amount of education for his son Richard, who during his first residence in Manchester, was employed by a wood turner in Salford to turn the wheel. In his master's absence, he tried occasionally to work at the lathe, and thus taught himself wood turning, in which art he always thought he excelled any other man. About the year 1809, he was engaged as a pattern-maker at the iron works of the late Mr. John Wilkinson, at Bradley, and at Gospel Oak, near Bilston, Staffordshire. When the late Mr. Aaron Manby commenced the foundry trade, and the building of steam engines at the Horseley Iron Works, Tipton, he engaged Mr. Roberts as a leading hand in the pattern-shop; and the introduction of new tools in that rising manufactory most probably contributed to directing his attention to labour-saving machines. For the purpose of obtaining a greater insight into the construction of steam engines, he removed to London, where he worked, chiefly as an iron-turner, first at Mr. Holtzapffel's, and then at the engine factory of Messrs. Maudslay and Field, where, under such masters, he enjoyed ample opportunities of extending his mechanical knowledge, among which should be prominently mentioned the privilege of working at the block machinery of the late Sir Isambard Brunel, in which may be found the germ of all subsequent labour-saving machines. All this while he had striven hard to acquire some amount of education, facilities for which had been denied to him during early life. Feeling that Manchester afforded the widest field for an inventive genius, he returned to that place and commenced business on his own account in Deansgate, as a lathe and tool maker, and as a general turner, in which capacity he frequently afforded valuable counsel and assistance to mechanical inventors by whom he was employed. Here he made the first machine for planing iron, which is still preserved in the Museum of Patents, South Kensington, also the back-geared lathe head-stock, having

the cone pulley running loose upon the spindle, and likewise an improved screw-cutting lathe. His slotting machine, and wheel-cutting engine soon followed, and these, with his improvements in the slide lathe, may be regarded as among the most important of the aids which his inventive talents have given to construction. This series of inventions introduced a precision, celerity, and cheapness into the production of machinery never before known, the results extending not only to the largest engines of ocean steamships, and to the endless machinery of the great factories of Lancashire, but also down to the railway-ticket press and the sewing-machine. Up to the year 1823, Mr. Roberts carried on business under the firm of Hill, Roberts, and Co.; after 1824, it became Sharp, Roberts, and Co., for his great talents and practical abilities having become well known, Mr. Roberts was invited to enter into partnership with the late Mr. Thomas Sharp, in conjunction with whom the Atlas Works, still ranking among the largest and most productive mechanical engineering factories in the kingdom, were established. Here, in 1825, in consequence of the formidable strikes among the hand-mule spinners, Mr. Roberts was led to the production of perhaps the most ingenious, as it has been one of the most valuable machines in the whole range of textile manufactures. This is the self-acting spinning mule, requiring only the attention of a child in the production of a thousand threads; many millions of spindles are now worked upon that principle in all civilized countries. Shortly after the opening of the Liverpool and Manchester Railway, Mr. Roberts directed his attention to the improvement of the locomotive engine, and many of his original refinements in its structure and workmanship may still be traced in the railway engines of the present day. One of his most valuable improvements introduced into the manufacture of machinery, and originally applied by him in 1825 in the construction of his spinning mules, was the application of standard templates to the forms and dimensions of every part. This system permitted the exact repetition of every portion of a machine to an endless extent, and it is that whereby the Enfield rifle is now made under so perfect a division of labour, that any one of a hundred thousand like parts fits exactly any one of an equal number of corresponding parts. The connection with the Atlas Works was dissolved on the decease of the senior partner, the late Mr. Thomas Sharp, in 1843, and from that date Mr. Roberts carried on business at the Globe Works, where, for a short period, he had the assistance, as partners, of Mr. B. Fothergill, and Mr. J. Dobinson; those gentlemen, however, soon retired from the concern, which was wound up in 1852, from which time Mr. Roberts practised in London as a Consulting Engineer, having as a partner for some time Captain T. E. Symonds, R.N.

During his long and active career he had, in some way or other, been connected with most of the mechanical improvements of the period. Thus, in 1847, at the request of the contractor for the great tubes of the Conway Bridge, Mr. Roberts produced the "Jacquard Punching Machine,"[1] an automatic tool of great power, whereby the rivet-holes in a large plate are punched to any required pattern and pitch, without need of templates or marking, and with a precision which enables any two of a thousand plates to be riveted together without subsequent correction of the rivet-holes, as had always before been necessary. Without this invention the tubes of the Conway Bridge could not have been completed in time, while their strength was also increased, and their cost of construction was reduced. The same punching machinery was employed in the construction of the Boyne Viaduct, the Victoria Bridge over the St. Lawrence, at Montreal, and for the Jumna Bridge of the East Indian Railway.

In 1852, he designed and made widely known his improved plans for ocean steamships of large size, with the improved form of bow now adopted by our own and by the French naval authorities, and having besides double keels and twin screws, with independent engines, as applied with remarkable success in several steam-vessels of recent construction.[2] These plans were for some time urged upon the Admiralty, and in 1855, they were submitted by Mr. Roberts, in person, to the Emperor of the French, who examined them critically, and in whose navy some of their peculiarities have been already adopted. It is needless to say that neither for these, nor for any of the numerous inventions which have proved of such eminent utility to his country, did Mr. Roberts ever receive any recognition from the Government: not even "the little bit of ribbon," which foreign sovereigns are so well aware are efficient stimulants to exertion among all classes of men.

Mr. Roberts obtained nearly thirty patents in England, and his inventions were of the most useful and diversified kinds, including the following subjects:—Hand and power looms, machines for preparing and spinning fibrous substances, steam engines, locomotive carriages, apparatus for punching, perforating, and shearing metals, beetling and mangling machinery, clocks, watches, and other time-keepers, machines for hoisting weights, telegraphic communication, weaving and cutting plushes, velvets, carpets, &c., fluid meters, pumping apparatus, screw propellers, churns for agitating and evaporating fluids, turbines, hydraulic presses, steam-ships and other vessels, anchors, steam boilers, life-boats, war ships and their armaments, casks, machinery for cutting paper, leather, cloth, &c., for punching,

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xvii., p. 191.
[2] *Ibid*, vol. xiii., p. 39.

drilling, and riveting, omnibus and other carriages, folding fabrics, mechanism for engraving and otherwise copying paintings and other designs on flat and curved surfaces, &c. &c.

Mr. Roberts was a man of extraordinary energy of character and of singleness of view. Confidence in his own powers prevented his admitting any insuperable difficulties: disappointment never checked him, and his industry was unceasing. The elements of commercial success were, however, wanting in his character, and although at one period he had amassed some property, it was almost all expended in experiments, and in the later years of his life he was in straitened circumstances. Still he worked on without repining: he felt that he was blessed in a daughter, whose filial piety and affection made up for all the worldly crosses he experienced. That excellent lady, Miss Roberts, devoted her life to her duty to her father, and in her arms he expired on the 11th of March, 1864, in the 75th year of his age.

Mr. Roberts joined the Institution of Civil Engineers as a Member, on the 20th of March, 1838. His residence in the country prevented his frequent attendance at the meetings, but whenever he was in London he made a point of taking part in the discussions, when his opinions and his reminiscences of the origin of inventions were always listened to with attention.

The career of Mr. Roberts was remarkable, and it should be carefully written by some one who could investigate impartially the numerous inventions and improvements to which claim could justly be laid for him, and who, at the same time would, with equal justice, show where his inventions have been pirated.

Mr. WILLIAM SIMPSON, the sixth son of the late Mr. Simpson, the well-known Engineer of the Chelsea and other Waterworks, was born at Chelsea on the 29th of July, 1809. He was brought up in the office and upon Engineering works under his brother, Mr. James Simpson (Past-President Inst. C.E.), and was by him placed at the head of the engine and machine manufactory in Pimlico, of which he was admitted as a partner. From these works proceeded several powerful and very good pumping engines, and a large quantity of other kinds of machinery. Ultimately Mr. William Simpson seceded from the Grosvenor Works and created for himself an establishment near Woolwich, for the construction of iron vessels, boilers, bridges, &c. It was on his return from these works on the evening of Saturday, May 7th, 1864, that the accident occurred by which he lost his life. He was observed to be sitting dozing on the rail of the steamer, and it is supposed that he lurched forward and, in endeavouring to

recover himself, he fell overboard. It was nearly a week before the body was recovered.

Mr. W. Simpson joined the Institution of Civil Engineers as an Associate on the 10th of February, 1829, and was transferred to the class of Members, on the 7th July, 1838. He served the office of Auditor of Accounts in 1838 and again in 1840. He was much attached to the Society, was a frequent attendant at the meetings, and always took a lively interest in the proceedings.

He was an amiable man, and his unfortunate decease, in his fifty-second year, caused great pain to his family and friends.

Mr. WILLIAM BAGNALL was born at Darlaston, in the county of Stafford, on the 4th of April, 1797. He was the second son of Mr. John Bagnall, a coal and iron-master, in the parishes of West Bromwich and Tipton, who, by his own unaided perseverance and energy, had raised himself to an important position in the iron trade of South Staffordshire; and who, with the sense of right which pervaded his character, admitted five of his sons into copartnership with him on the 24th day of June, 1828; and died on the 23rd of November, in the following year. At the death of his elder brother John, on the 4th of February, 1840, Mr. William Bagnall became the senior member of the firm of John Bagnall and Sons, the owners of the extensive collieries and ironworks producing the quality of iron so well known as the I. B. Crown brand. This honourable position he continued to hold until his death, which occurred suddenly, after only a few hours' illness, at Hamstead Hall, Handsworth, on the 12th day of August, 1863, at the age of sixty-six. At an early age Mr. Bagnall entered the ironworks of his father, and having naturally a mechanical turn of mind, soon made himself practically acquainted with all the intricacies of the construction and management of blast furnaces, forges, and mills, and of the working of collieries; and when any difficulty arose with regard to the machinery employed, his opinion was very valuable. On the introduction of railways the firm early directed their attention to the manufacture of rails, and thus were brought into contact with the late Mr. George Stephenson. Even in his school-days William Bagnall was remarkable for his genial, kindly disposition, and in after-life, when he had the means as well as the inclination to do good, he naturally took great interest in those institutions which he knew to be for the moral and spiritual welfare of the workpeople and their families. Schools were built at Golds Hill and Caponfield, at a cost of more than six thousand pounds, for the education of the children, and being also licensed for divine worship for both parents and children, two chaplains were so

usefully employed in connexion with the works, that the benevolent projector of this too infrequent care for the spiritual welfare of the working class, could rejoice in the success which attended so noble an undertaking. Mr. William Bagnall will be long remembered for his uniform good temper, his generous and happy disposition, and his kindness of manner towards all with whom he was connected; and he will ever be considered as having been the friend as well as the benefactor of the poorest of his workmen. This was evinced in many ways; and so much was he beloved by the poor, and his loss lamented, that thousands manifested their affectionate respect, by attending his funeral, which took place at All Saints Church, West Bromwich. Mr. Bagnall was elected an Associate of the Institution of Civil Engineers, in the year 1841, but his residence in the country prevented his frequent attendance at the Meetings.

Mr. FREDERICK LAWRENCE, the fourth son of the late Mr. Alderman William Lawrence, was born in London on the 4th of April, 1828. He was educated at the City of London School, which he entered on the day of its opening, February 2nd, 1837, and after passing through the junior school, and obtaining several prizes, he took a high position in the senior class, standing on one occasion second for a scholarship, and on another second for the senior mathematical medal and prize. He afterwards entered University College, London, where he obtained the first prize for geology, for civil engineering, and for architecture, besides certificates for chemistry and other branches of knowledge. In the year 1845 he was articled to Messrs. Walker and Burges, and was employed under them for two years in superintending extensive drainage works in the Middle Level, Cambridgeshire, and afterwards on the harbour and pier works at Dover, Plymouth, and Spurn Point, and he subsequently assisted in carrying out many other important works. Of one of these, the Blackfriars Landing Pier, he communicated an account to the Institution of Civil Engineers,[1] and for it he received a Council Premium of Books.[2]

Whilst at the Middle Level, his attention was directed to the defects in the working of the sluices, and having been allowed to fix, by way of experiment, a small sluice constructed on a novel principle, it was found to act so efficiently, that he patented the invention. The large sluices at the Commercial Docks were then constructed on this principle,[3] and for the system as there demonstrated he

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. ix., p. 144.
[2] *Ibid.*, vol. x., p. 66.
[3] *Ibid.*, vol. xvii., p. 401.

obtained Honourable Mention at the Great Exhibition of 1862. The invention consists in using the head of water as the motive power for raising and lowering the sluices. He also invented and patented, in conjunction with his brother and Mr. W. Davison, a modification of the rotary engine, which consists in making the cylinder a true epicycloidal curve.

In 1852 he entered into partnership with his brother, Mr. Alfred Lawrence, and they jointly established the City Ironworks, London, where he was enabled to turn to practical account his mathematical and engineering knowledge. In 1857 he was elected an Associate of the Institution of Civil Engineers, by many of the Members of which he was well known and esteemed. Some years previously he had joined the Society of Arts, in the proceedings of which he took so great an interest, that in 1863 he was elected a Member of the Council of that Society.

Mr. Lawrence died, after a few days' illness, at the Mansion House, London,—where he was residing during the mayoralty of his brother, Mr. Alderman William Lawrence,—on the 31st of May, 1864, aged thirty-six, deeply lamented by his numerous friends, who valued him for his great talents, for his persevering energy, but above all for his high integrity and upright character. His modesty and kindness of manner endeared him to all who knew him, and his memory will long be cherished, not only by his sorrowing relatives, but by all those who were associated with him in many benevolent works, and who admired the example he showed of pure moral life sustained by high religious principle.

Mr. THOMAS TELFORD MITCHELL, the youngest son of the late Mr. John Mitchell, Engineer and General Inspector to the Parliamentary Commissioners for Highland Roads and Bridges, was born at Inverness in the year 1815. He served a regular pupilage under his brother, Mr. Joseph Mitchell (M. Inst. C.E.), who had succeeded to the appointment on their father's decease, and he was employed for some years in the office and on works both for his brother and for Mr. Leslie (M. Inst. C.E.). He was then for two years Resident Engineer on the Newtyle and Coupar Railway, and subsequently for eight years was engaged in the same capacity on the Slamannan Railway, under Sir John Macneill (M. Inst. C.E.). He was next for several years on the staff of Messrs. Stephenson, Brassey, and Mackenzie, contractors, and had charge, for them, of the construction of the Scottish Central Railway tunnel at Perth, and of the works on the Scottish Midland from Perth to Forfar.

On the death of his brother, Mr. Alexander Mitchell,[1] in 1848,

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. ix., p. 103.

who was established at Perth as a Civil Engineer, Mr. Thomas Telford Mitchell succeeded to the business, and had the charge of most of the principal roads in the district, besides acting generally as a Civil Engineer, in which capacity he laid out and constructed the railroad from Dunblane to Callander, 13 miles. During the latter part of his life he became a contractor on his own account, and constructed several branch lines of railway in the county of Perth, and a length of 30 miles of a railway in Galloway.

Mr. Thomas Telford Mitchell had thus had considerable experience in the profession, and he was considered a good practical Engineer. He was elected an Associate of the Institution of Civil Engineers on the 24th of June, 1845, and his decease took place on the 31st of December, 1863.

Mr. JAMES SHERRIFFS was born on the 17th of August, 1801, at Persley, near the manufacturing village of Woodside, about two miles north of Aberdeen. As the circumstances of his parents did not enable them to bestow an expensive education on their son, he was taught from an early period of his life that he would have to earn his livelihood by the labour of his hands. When he was about fifteen years of age, he was apprenticed for six years to Mr. Carter, millwright and engineer in Aberdeen, with whom he continued to work for two years after the term of his apprenticeship had expired. During this period he was remarkable for diligence and attention, and he soon attained such skill of hand that, long before he had served his time, he excelled, in rapidity and dexterity, the best workmen in Mr. Carter's employment. Nor, while he thus attained excellence as a workman, did he neglect the cultivation of his mind, but by regular attendance at the classes of the Aberdeen Mechanics' Institution, he made up for the deficiencies of his earlier education. In the spring of 1825 he came to London, where, soon after his arrival, he obtained employment under the late Mr. Maudslay. That eminent Engineer, himself a dexterous workman, as well as a brilliant mechanic, appreciated the skill which James Sherriffs displayed, and he was employed as a special assistant in working out schemes on which Mr. Maudslay's ingenuity was exercised. In the employment of Messrs. Maudslay, Sons, and Field, Mr. Sherriffs passed thirty-eight years—in fact the remainder of his life. From a workman he was in 1830 promoted to be foreman of a department, and in 1845 he was entrusted with the general superintendence of the factory. After about thirty-five years passed in that service, Mr. Sherriffs' health began to fail, but he never relaxed in his attention to the works.

He seemed indeed ever to have the interests of the firm more at heart than if they had been his own. From early morning until late at night, with rare and brief holidays, and those taken only when illness rendered them absolutely necessary, he gave undivided attention to the large and varied works carried on in the establishment which he superintended. He may be said to have died in harness, for his labours were unremitting till, in the spring of 1863, he was struck with the illness from which he never recovered. He suffered, with fortitude, great pain and extreme debility, the result probably of exhaustion produced by a life of unceasing labour and anxiety; and, after lingering a few months, he expired on his own birthday, the 17th of August, 1863, having exactly completed his sixty-second year. It is sadly interesting to remark, that he died on the day on which his illustrious master, Mr. Joshua Field (Past President Inst. C.E.) was buried, having survived him only a week.

Mr. Sherriffs was elected an Associate of the Institution of Civil Engineers in the year 1851, and was very regular in his attendance at the meetings. The leading feature of his character was a modest diffidence, which throughout life held him back, while others, by no means superior in talents or acquirements, took high positions in the engineering world. He was eminently quiet and unpretending, and thus a due estimation of his capabilities was confined to those who knew him intimately. He was cautious, painstaking, and assiduous almost to a fault, but these were qualities which were of the greatest value to his employers, and which they highly appreciated. In disposition he was most kind and generous, and in manner he was courteous and refined. The men who worked under him never heard a rough word pass his lips, and yet they knew him to be strict and resolute, and they obeyed him not only without a grudge, but with reverence and love. Perhaps of all who lamented the death of James Sherriffs, none mourned more sincerely and with better reason than the foremen and workmen whose labours he had so long, so successfully, and so kindly directed.

Mr. ALFRED THOMPSON was born at Queen's Row, Chelsea, in the year 1818, and received the greater part of his early education under Mr. Sheepshanks, at the St. Peter's Grammar School, Eaton Square, Pimlico. He was articled to his father, Mr. George Thompson, of the Eccleston Ironworks, Pimlico, and continued in his service until 1842, when he was admitted into the firm of G. Thompson and Sons; and from the year 1844 to the period of his decease, he was the managing partner, in addition to which duties, he practised as a Civil and Consulting

Engineer. He was extensively employed in designing and constructing sanitary apparatus, and made the name of his firm familiar in London to every trade connected with gas and water supply, sewage works, &c. His stove for cooking by ordinary coal-gas was the first successful apparatus of the kind, and it was largely used. In 1854 he was elected "Inspector of Furnaces" for the metropolis under "The Smoke Nuisance Act," and he continued to act in that capacity until 1858. In 1855 he drew up a Report on "Extension of the Smoke Nuisance Act," addressed to Sir Richard Mayne, in which he proved that smoke might be prevented in any kind of manufacture in London, and urged the authorities to advocate the extension of the Act to the large works adjacent to the City. Mr. Thompson's knowledge of chemistry and mechanics rendered him peculiarly fitted for the duties of Inspector under the Act, and he performed them fearlessly.

In 1861, when the spire of Chichester Cathedral fell, Mr. Thompson made a careful examination of the ruins, and after testing part of the material, he discovered that the limestone with which the spire had been built, had been laid constructively in its weakest position, and that it was a wonder how it existed so long under such conditions. The result of his testing and analysis was laid before a Meeting of "The Royal Institute of British Architects," and was published in the "Builder," August 13th, 1861.

In 1856 he was elected an Associate of the Archæological Society; and from the memoir of him, which is printed in the Obituary of the Proceedings of that Society, he appears to have been an intelligent and indefatigable member.

He joined the Institution of Civil Engineers, as an Associate, on the 29th February, 1838, and was a constant attendant at the Meetings, taking great interest in the proceedings. He was a good mechanic, and by reading and frequent attendance at the scientific Meetings of the metropolis, he acquired a considerable insight into the progressive improvements of the period. He was an amiable man, and his decease, on the 4th of January, 1864, in the forty-sixth year of his age, was severely felt by his family and friends.

*** The Memoirs of those deceased Members which have been omitted, in consequence of the difficulty of procuring information from their friends, will, it is hoped, appear in the next Volume.

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